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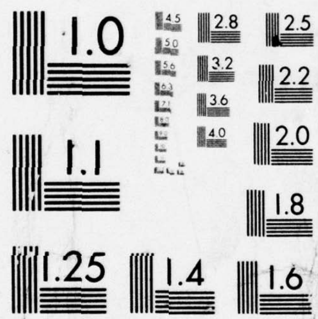

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TECHNICAL REPORT Y-74-1

ENVIRONMENTAL ANALYSIS AND ASSESSMENT OF THE MISSISSIPPI RIV 9-FT CHANNEL PROJECT BETWEEN ST. LOUIS, MISSOURI, AND CAIRO, ILLI

by

Jeffrey H. Johnson, R. Charles Solomon, C. Rex Bingham,
Billy K. Colbert, William P. Emge, David B. Mathis, Ross W. Hall, Jr.

Environmental Effects Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

November 1974

Final Report

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The Mississippi River 9-ft channel project was authorized by the River and Harbor Acts of ~~21 January~~ 1927 and ~~3 July~~ 1930, for the purpose of obtaining and maintaining a 9- by 300-ft channel for navigation from the confluence of the Missouri River (St. Louis, ~~Missouri~~) to the confluence of the Ohio River (Cairo, ~~Illinois~~). The main channel will be contracted to 1500 ft between riverward ends of dikes throughout the study area in order to maintain

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20. ABSTRACT (continued)
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the 9-ft depth during periods of low flow. A comprehensive study of the historical geomorphology supplemented by physical models of the river and side channels was made ~~by Colorado State University~~ to determine the physical impact of river contraction works on river morphology and behavior. An intensive study of the terrestrial flora and fauna was conducted by Southern Illinois University to inventory the existing organisms and communities located in the unprotected floodplain and to assess the impacts of operation and maintenance activities on these organisms and communities. In addition, the aquatic flora and fauna were studied by the Missouri Department of Conservation and the Waterways Experiment Station to inventory the aquatic communities present in the study area and to assess the importance of side channels to the riverine ecosystem. Biological, physical, chemical, and morphometric data, collected from side channels and river border areas, were subjected to various statistical analyses. The relative biological importance of each side channel established by ranking procedures provided a rational choice of those side channels that could provide maximum benefit to the river's ecology. Operation and maintenance activities of the St. Louis District in the Middle Mississippi include maintenance dredging, disposal of dredged material, and construction and maintenance of levees, dikes, and bank revetments. These activities were examined and the potential environmental impacts resulting therefrom were discussed. Based upon the overall results of these studies, the need for new and more intensive studies was obvious. These additional studies would define to a greater degree the impacts of the 9-ft channel on the environment.

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PREFACE

The U. S. Army Engineer District, St. Louis (SLD), has the responsibility to construct and maintain the Middle Mississippi River 9-ft channel navigation project between St. Louis, Missouri, and Cairo, Illinois. SLD has requested the Environmental Effects Laboratory (EEL) of the U. S. Army Engineer Waterways Experiment Station (WES) to conduct an environmental inventory and assessment of the 9-ft project area. Certain parts of the inventory and assessment were performed under contract by the Missouri Department of Conservation, Southern Illinois University, and Colorado State University.

The study reported herein was conducted from June 1972 to March 1974 by an interdisciplinary study team from WES, SLD, Missouri Department of Conservation, Southern Illinois University, and Colorado State University. This report is part of a series of reports resulting from that interdisciplinary effort. The other reports in this series, all sponsored by SLD, are as follows:

(a) Contract Report Y-74-1, "Evaluation of Three Side Channels and the Main Channel Border of the Middle Mississippi River as Fish Habitat," March 1974

(b) Contract Report Y-74-2, "Geomorphology of the Middle Mississippi River," July 1974

(c) Contract Report Y-74-3, "A Survey of the Fauna and Flora Occurring in the Mississippi River Floodplain Between St. Louis, Missouri, and Cairo, Illinois," August 1974

(d) Contract Report Y-74-4, "Study of Importance of Backwater Chutes to a Riverine Fishery," August 1974

(e) Technical Report M-74-5, "Computer-Calculated Geometric Characteristics of Middle-Mississippi River Side Channels," Volumes I and II, June 1974

(f) "Physical, Biological, and Chemical Inventory of Twenty-Three Side Channels and Four River Border Areas, Middle Mississippi River," in preparation

(g) "Inventory of Physical and Cultural Elements, Middle Mississippi River Floodplain (River Reach: St. Louis, Missouri, to Cairo, Illinois)," in preparation

Parts II-IV of this report are overviews of the reports of each agency or university. Data from Parts II-IV were used in preparing the remainder of the report. Information from Parts II and IV was repeated as required later in the report so that the later parts could be used by SLD in preparing an Environmental Impact Statement.

This report was prepared by J. H. Johnson, R. C. Solomon, C. R. Bingham, B. K. Colbert, W. P. Emge, D. B. Mathis, and R. W. Hall, EEL, under the general direction of Dr. John Harrison, Chief, EEL. Dr. Boyd Loadholt, Department of Biometry, Medical University of South Carolina, assisted with the statistical analyses. D. F. Bastian, Hydraulics Laboratory, WES, prepared the overview "Geomorphology," presented in Part II from the Colorado State University report.

BG E. D. Peixotto, CE, and COL G. H. Hilt, CE, were Directors of WES during the conduct of this study and the preparation and publication of this report. Mr. F. R. Brown was Technical Director.

CONTENTS

CONTENTS

LIST OF FIGURES

CONTENTS

CONTENTS

LIST OF TABLES

CONTENTS

LIST OF PLATES

CONVERSION FACTORS, METRIC (SI) TO U.S. CUSTOMARY AND U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

Units of measurement used in this report can be converted as follows:

Multiply	By	To Obtain
	Metric (SI) to U. S. Customary	
millimeters	0.03947	inches
square meters	10.76	square feet
liters	0.26418	gallons (U. S. liquid)
milligrams per liter	0.00013	ounces per gallon (U. S. liquid)
Celsius degrees or Kelvins	9/5	Fahrenheit degrees*
	U. S. Customary to Metric (SI)	
inches	0.0254	meters
cubic feet per second	0.02831685	cubic meters per second
miles (U. S. statute)	1609.344	meters
feet	0.3048	meters
square feet	0.092903	square meters

* To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following equation: $F = 9/5(C) + 32$. To obtain Fahrenheit from Kelvin (K), use: $F = 9/5(K - 273.15) + 32$.

ENVIRONMENTAL ANALYSIS AND ASSESSMENT OF THE MISSISSIPPI RIVER 9-FT CHANNEL PROJECT BETWEEN ST. LOUIS, MISSOURI, AND CAIRO, ILLINOIS

PART I: INTRODUCTION

Background

1. In 1927, the Corps of Engineers was authorized by Congress to construct and maintain a 9-ft*-deep, 300-ft-wide channel for navigation from the confluence of the Missouri River to the confluence of the Ohio River. The River and Harbor Act of 2 March 1945 modified the project by providing for the construction of the Chain of Rocks Canal and Lock No. 27. A later modification, contained in the River and Harbor Act of 3 July 1958, provided for the construction of Low Water Dam No. 27.

2. The U. S. Army Engineer District, St. Louis (SLD), is required by the National Environmental Policy Act of 1969 (Public Law 91190) to prepare an Environmental Impact Statement for the construction and maintenance of the 9-ft channel. SLD requested the Office for Environmental Studies, now part of the Environmental Effects Laboratory (EEL), of the U. S. Army Engineer Waterways Experiment Station (WES) to conduct an environmental inventory and assessment of the effects of operation and maintenance activities on the environment in the project area. The inventory and assessment were designed to provide input for the impact statement as well as to establish suggested procedures for environmentally compatible operation and maintenance of the channel.

3. EEl assembled an interdisciplinary team that included personnel from SLD, WES, Missouri Department of Conservation (MDC), Southern Illinois University (SIU), and Colorado State University (CSU). Contracts were made with MDC, SIU, and CSU to perform and to provide reports on certain parts of the inventory and assessment.

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* A table of factors for converting U. S. customary units of measurement to metric (SI) units of measurement and metric (SI) units of measurement to U. S. customary units is presented on page 9.

Purpose

4. The objectives of the study were to:

   a. Provide a reference source for the preparation of an Environmental Impact Statement.

   b. Establish a comprehensive data base.

   c. Use the results of the study for better environmental planning.

   d. Describe the environmental impacts of construction, operation, and maintenance of the 9-ft channel.

   e. Recommend new and/or more intensive research needs in the project area.

Scope

5. The authorized reach includes 195 miles of the Mississippi River between the mouth of the Missouri River above St. Louis, Missouri, and the mouth of the Ohio River at Cairo, Illinois (river mile 0). The project area for this study extends from the Jefferson Barracks Bridge near St. Louis (river mile 168.7) to Cairo and covers the entire Mississippi River floodplain within this reach. This reach of the river will be referred to as the Middle Mississippi River (Figure 1). The original unprotected floodplain, which is primarily in Illinois, generally has been reduced to about one mile in width by levees throughout the project area (Plates 1-11).

6. Parts II, III, and IV of this report contain overviews of individual reports prepared by CSU, SIU, and MDC, respectively. These parts describe the geomorphology, the terrestrial flora and fauna, and the aquatic flora and fauna, respectively, of the project area and the adjacent unprotected floodplain. Extracts were made from these reports, but quotations were not marked in order to improve the continuity of the narrative.

7. Part VIII represents an overall assessment of the side channels and the environmental impacts of construction and operation and maintenance activities required by the 9-ft channel.

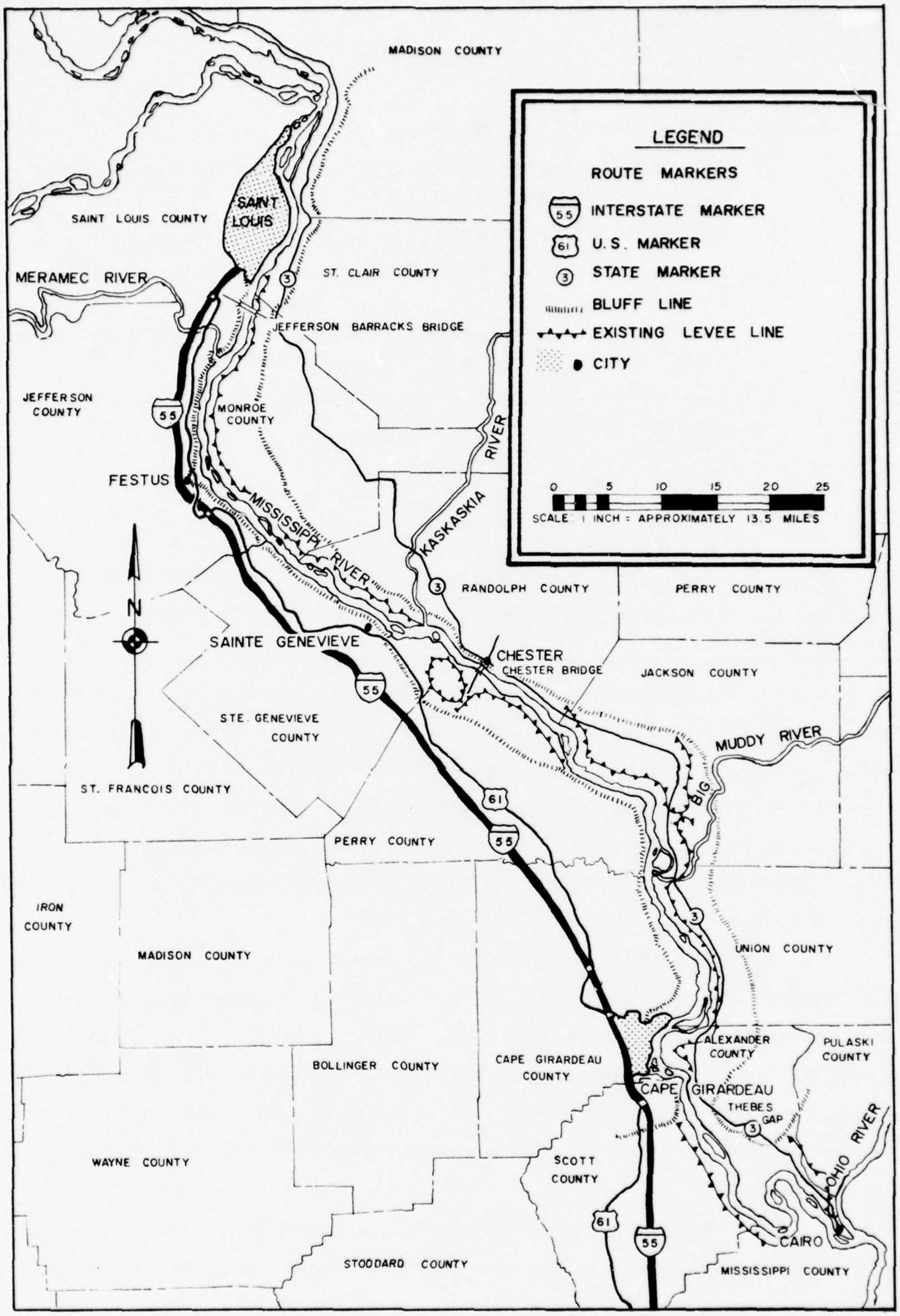

Figure 1. Mississippi River floodplain and levee system

PART II: GEOMORPHOLOGY

8. CSU conducted a study of the geomorphology of the Middle Mississippi River, which included physical model studies of the side channels and dikes. This part is a summary of the CSU study.

9. This part considers the Middle Mississippi River before and after man-made changes and the effects of these changes upon the river. Emphasis was placed on the life history of side channels in terms of river flows, sediment transport, and growth of vegetation to provide a basis for evaluating the physical changes in the river system. The final portion summarizes the results of model studies of side channels whereby effects of geometry and number of dikes were studied to determine whether side channels could be self-maintaining.

Natural- and Developed-River Periods

10. Until the twentieth century, man-made changes to the Middle Mississippi were not of sufficient magnitude to change the river; thus the river during this period is referred to as the natural river. Because twentieth-century changes have altered the hydraulic characteristics of the river, this century is referred to as the developed-river period.

11. During the 1800's, efforts were directed primarily to flood protection which resulted in a protective levee system. Navigation on the river had always been important; but vessels had increased gradually in size and numbers until in 1927 it was necessary for Congress to authorize a 9-ft-deep by 300-ft-wide channel. Due to natural shoaling at crossings, maintenance dredging has been necessary. Attempting to reduce shoaling, the Corps has placed dikes in wide sections of the river in order to constrict the width and restrict flows that otherwise would provide far more erosion power and result in a deeper channel. To protect banks from caving and to prevent extensive natural meandering of the river, revetments have been strategically placed, primarily on the outside of bends. The combination of dikes and revetments has virtually

locked the river into a fixed position. However, both dikes and revetments are subject to destruction, especially by floods and ice flows.

12. By 1972, main-line flood control levees were complete where necessary. There were 122 miles of revetments and over 800 dikes with a total linear length of 91 miles.

Geometry

13. To help determine changes of the Middle Mississippi River, maps from 1821, 1888, and 1968 were used to compare the changes in surface area and river width. The surface areas and width increased from 1821 to 1888, when they obtained maximum magnitude as a possible result of large floods. From 1888 to 1968, the surface areas and widths were reduced to their smallest ever because of river-training efforts by the Corps of Engineers.

14. A riverbed survey of a 14-mile reach from 1888 to 1968 shows an average lowering of 11 ft as a result of the man-made contractions of the river width.

15. The major source of sediment to the Middle Mississippi is the Missouri River. The suspended load is approximately 50 percent clay, 35 percent silt, and 15 percent fine sand. The bed load is fine sand. Although there are no records for comparing the amount of sediment supply prior to and after establishing the reservoir system on the Missouri Basin, the system has probably decreased the sediment supply drastically, which would account for lowering of the riverbed in the Middle Mississippi River.

Discharge

16. The highest recorded discharge at St. Louis (river mile 175) was 1,300,000 cfs in 1844 with a corresponding stage of 41.3 ft. Due to river training, a similar discharge today is predicted to produce a stage of 52.0 ft.

17. The net effects of upstream developments on the flows in the Middle Mississippi River at St. Louis are reflected in the St. Louis discharge records. These effects are as follows:

a. The average annual peak flood discharge has not changed significantly in 110 years. On the average, the

present-day peak floods are only slightly lower than previous ones.

b. Large flood flows are not occurring as frequently now as in the past. In the decade between 1850 and 1860, there were three flood peaks greater than 1,000,000 cfs. Flood flows in excess of 1,000,000 cfs have not occurred since 1903.

c. The mean annual discharge has not changed in 130 years.

d. The annual minimum flow has been increasing slightly during the 130 years of record (1843 to 1973).

18. In general, the conclusion is that construction of storage reservoirs, levees, and dikes; land-use changes; and any climatic changes have not, in aggregate, significantly changed the average annual flow in the Middle Mississippi. In terms of flood control, the effect is that very large and very small peak flood discharges were more commom in the natural river than in the river today.

River stages

19. The St. Louis river stage records, begun in 1843, were kept intermittently until 1861; after 1861, continuous records have been kept on a daily basis. A gage reading of zero at the Market Street gage is 379.94 ft above mean sea level (msl).

20. The annual maximum stage at St. Louis has been increasing only slightly throughout the 130 years of records. The variations in annual maximum stages are greater now than in the past. The highest recorded stage at St. Louis was 43.3 ft in 1973.

21. The trend of the annual minimum stages has been downward during the period of record. The minimum stages are now, on the average, 6 ft lower than in the 1860's and the 1870's. The lowest minimum stage at St. Louis was -6.2 ft recorded on 16 January 1940.

22. The study of the daily stage versus duration curves reveals that, on the average, daily stages are lower now than a century ago. In the period 1861-1900, the stage equaled or exceeded 50 percent of the time was 11 ft, whereas in the later period, it was 8.5 ft. There have been more very low and very high stages in the last 70 years than in the first 40 years of record.

23. The changes in river stage at St. Louis in the last century

are due mainly to the rock and/or pile dikes and the levees. Construction of rock and pile dikes causes sedimentation in the dike field. Trees and willows grow on the deposits, stabilize them, and encourage additional deposits whenever the area is flooded. In most cases, the ultimate effect of the dike field is to cause the river to develop a new bankline at the extremity of the dike field, resulting in reduced channel width and a lowering of the riverbed level.

24. The levees have isolated the major portion of the floodplain from the river channel, so that all floodwaters are now confined to the river channel and that portion of the floodplain between the channel and the levees. For discharges ranging from 300,000 to 500,000 cfs, the present increased stages are due to dikes. For discharges in excess of 500,000 cfs, the higher stages are a result of the combined effect of dikes and levees.

River stage versus discharge

25. The stage-versus-discharge relationship has changed markedly as a direct result of river constrictions and sediment-supply interruptions. Constrictions have resulted in riverbed lowering due to the increased discharge and sediment transport capacity per unit width. Dams on the Missouri River have aggravated the situation by reducing the sediment supply. Therefore, during low discharge (less than 300,000 cfs), the stages are lower in the developed river. The natural and the developed river have a coinciding stage and discharge of 19 ft and 290,000 cfs, respectively, as recorded in 1837 and 1946. For the developed river, any discharge above 300,000 cfs results in higher stages than was experienced for similar discharges in the natural river.

Side Channels

26. In order to achieve the 9-ft-deep low-water navigation channel in the study area and to reduce maintenance dredging of the channel, the unobstructed river channel will be narrowed to a width of approximately 1500 ft by projecting rock dikes from one or both riverbanks into the channel. Some water areas will exist within the dike fields;

thus the actual water surface width will be greater than 1500 ft but may be different for each reach of the river. When necessary, the opposite bankline will be protected with revetment to control its migration. In planning these contraction works, the Corps is endeavoring to optimize the project plans to meet the standards of conservation and flood control interests as well as those of navigation.

27. The planned contractions on the Middle Mississippi River will produce bank-full stages at lower discharge. Also, the planned contractions will lower the bed elevation of the channel and will produce lower stages at low discharges. In the past, river contraction works have created new islands, side channels, and floodplain lands.

28. In the Middle Mississippi, some side channels were natural in origin. However, many of the more recent side channels are the result of dike fields constructed by the Corps of Engineers to improve the navigation channel.

29. The interest concerning the habitat for biological communities provided by the side channels leads to the questions of how side channels form; how they change with time; and how navigation improvement works affect them. It is especially important to understand why some natural side channels have existed for more than 100 years whereas others fill and are obliterated within a decade.

Natural Side Channels

30. In the natural river, side channels and islands were formed because of a complex series of events. Two of the ways in which a natural channel becomes divided are explained in the following section. The first is the division of a straight channel into two channels; the second is the division of a meandering channel by the development of a side channel at a bend.

Straight channels

31. In the early history of the Middle Mississippi River, the depositional environment necessary to produce a divided channel was often created by floating trees or other objects snagging on sandbars

during flood recession. The bed current would then sweep around the obstruction and deposit sediment in its wake. If succeeding floods did not remove the deposition and vegetation was established, an island and a side channel were formed.

32. An example of the sequence of events in the formation of an island and later destruction of a side channel in a straight reach of undeveloped river would be as follows:

- a. Existence of a depositional environment within an existing channel.
- b. Arrival of a local disturbance, for example, a sunken barge, which triggered rapid deposition of a sandbar.
- c. Establishment of vegetation on the bar. At this point, the sandbar became an island separated from the mainland by a side channel.
- d. Encroachment of the island and mainland banks into the side channel.
- e. Deposition of mud over the whole area when flows became essentially slack water; that is, the side channel became a backwater channel.
- f. Ultimate merger of the island with the mainland floodplain, thus ending the existence of the backwater channel.

Meandering channels

33. In a meandering river, the division of the main channel into two or more channels can occur at bends, meander loops, and straight reaches. The formation of side channels at a bendway may be due to bankline migrations, but side channels also occur in the absence of bankline migrations. The water hydrography plays an important role in the formation of side channels in natural rivers, but side channels form in the laboratory model bendways when the discharge is held constant. In some bends, the side channel captures the main channel flow and leaves the main channel with only a side channel status. In other cases, the side channel at a bendway fills rapidly. Some of the reasons for formation of secondary channels in a meandering river are discussed below.

34. Point bar cutoffs. Point bar cutoffs occur during high flows because at higher velocities the flow momentum encourages a less tortuous river path. That is, during floods, the flow straightens out in the

river channel. Some of the floodwater short-circuits the low-water thalweg around the outside of the bend and develops a channel across the point bar adjacent to the convex bank. The receding flow waters leave the main channel on the concave side, a middle bar, and a channel on the convex side of the bend. If the middle bar becomes vegetated, a chute channel is formed.

35. At lesser flows, the channel on the convex side of the bend fills with sediment carried by slow-moving, sediment-laden bed currents flowing around the inside of the bend.

36. Meander loop cutoffs. The meander loop chute cutoff is formed by the same process as the point bar cutoff but on a larger scale. During floods, the momentum of the surface water carries it across the neck of the meander loop. If the short-circuiting water can scour out a channel, a chute cutoff of the meander loop is formed. This chute channel generally develops into the main channel and the meander loop channel becomes an oxbow lake.

37. Potential for a meander loop chute cutoff is great where the length of the meander loop channel is many times the distance across the neck. The chute cutoff would be accomplished most likely by a large flood.

38. When a cutoff is the result of the migration of one bend into another, no chute is formed; the cross connection is a gooseneck cutoff or merely a cutoff. The meander loop abandoned by the cutoff becomes an oxbow lake.

39. Lateral bankline migration. If the bankline migration is normal to the river valley, side channels form on the inside of bends. The process of formation is different from that of the point bar cutoff. The point bar cutoff is formed by erosion, whereas in the lateral migration case, the side channel is usually a depositional feature on the inside of the bend. The size of the side channel is increased at times by floodwaters.

Summary

40. In summary, an alluvial river in its natural state can divide into two or more channels by the processes of either erosion or

deposition. The side channels so formed can grow in size and capture most of the discharge and become the main channel; they can deteriorate in size and become a part of the floodplain; or they can grow to the same size as the main channel and maintain that size. In the natural state, those side channels that are obliterated by deposition are replaced by new side channels caused by floods and/or river migrations.

41. In the Middle Mississippi, the river is no longer free to migrate and produce new side channels. There are no meander loops to be cut off by floods. Except for the major chute channels, natural side channels in the Middle Mississippi River are being filled with sediment. The major chute channels such as Cape Bend have achieved a size that indicates that they could exist for a long period of time.

Man-Made Side Channels

42. Today most of the more recent side channels in the Middle Mississippi River are man-made. These side channels form in and along the dike systems constructed to improve the river navigation channel. Dike fields are projected into the river channel to contract the river width at low flow. In the contracted form, the river thalweg remains in approximately the same low-flow position every year. Moreover, low-flow depths in the contracted river are deeper than in the broader natural channel.

43. The contraction of the Middle Mississippi River with dikes has eliminated most of the natural side channels. In many cases, these natural side channels have been replaced with man-made side channels that may be more favorable habitats for fish and wildlife. It may be beneficial to the river ecology to retain and maintain man-made side channels as well as the natural side channels.

44. A side channel produced by dike fields is often relatively short-lived. The dike fields and side channels fill with sediment rapidly because dike fields are usually located in areas of natural deposition. Once the side channel is filled with sediment, there is easy access to the island area. In many cases, the filled side channel area and the island area are converted to agricultural use. Thus,

the areas are no longer suitable as fish and wildlife habitats. Cleared areas provide less resistance to high flows than treed areas and are more efficient in passing large flows at lower stages.

45. The life history of side channels and dike fields is evident in all reaches of the Middle Mississippi River. Dikes were built in the Middle Mississippi after the close of the nineteenth century. In almost every reach, there are old dike fields that have been completely covered by sediment and vegetation and are now indistinguishable from the mainland; there are new and old dikes visible only where they cross backwater channels and at the main channel extremity; and there are new dike fields as yet not covered by sediments and vegetation. A side channel in a dike field passes through stages of development usually to a stage where the side channel is indistinguishable from the adjacent floodplain.

Model study

46. A detailed laboratory model study of the evolutionary development of side channels in dike fields was made by CSU in which the methods of prolonging the life of man-made side channels were studied. The CSU river research flume was a 20-ft-wide by 100-ft-long sand-bed flume; the bed material was 0.8-mm sand. A 6-ft-wide channel was formed in the sand, and the sand banks of the channel were stabilized with mortar. The model did not have a floodplain. The riverbanks in the model represented the riverbanks and levees or bluff lines in the Middle Mississippi River. Dike fields were built in different reaches of the river channel. Dikes were constructed with riverbed sand covered with a stabilizing mix of sand and cement. The dikes had a 1.5:1 slope on the upstream face and a 2:1 slope on the downstream face. The dike lengths were varied from 10 to 28 in., depending on the location of the dike. Dike crest elevations were established so that the dikes were submerged at high flows but exposed at low flows.

47. The flow rate in the model was varied between 0.25 and 1.5 cfs to reproduce the form of the yearly flow duration curve in the Middle Mississippi River. Although there was movement of sediment in the model crossings at low flows, sediment transport in the model was

significant only at higher flow rates. That is, except for a few bed adjustments, the low-flow discharge followed the channel established at higher flow rates.

48. In the model there was a small amount of clay mixed with the sand. This clay was moved as suspended load and was deposited in backwater areas where the currents were very slow. These clay deposits were very thin and did not change the geometry of the backwater areas appreciably.

49. The sand-bed model was operated in such a manner as to produce bars, scour holes, and other riverbed forms that occur in the Middle Mississippi River.

50. The model was not used to reproduce specifically any given reach of the river but instead to simulate typical sections of the river. In this manner, various dike and dike field arrangements were studied with model flow rates in the form of a long-term average hydrograph to test and observe qualitatively the river's response to the man-made structures and the development of natural channels.

<u>The single dike model</u>

51. Based on the model study, when a single dike is projected from one bank out into the channel flow, the flow velocities increase, especially around the nose of the dike. The increased velocity causes sand to be scoured from the region around the nose of the dike. Because the bed velocities at the nose of the dike are still less than the surface velocities, it is the sediment-laden bed-velocity layer that makes the turn into the lee side of the dike, where the flow expands and slows. On the lee side of dikes placed in natural depositional areas, the sediments are deposited and form a bar.

52. After the scour hole at the nose of the dike has reached an equilibrium depth, the flow field around the nose of the dike takes the normal bed materials moving in from above the dike and places these sediments on the bar. Thus, in the model, the bar continues to grow, even after the scour hole has ceased growing.

53. As soon as the bar is formed, a derelict channel is left in the area between the bar and the bankline. This channel accepts the

flow over the bar and drains that flow out the lower end. If the bar were to become vegetated or otherwise stabilized, the small channel between the bar and the bank would become a side channel. The future of the side channel would depend on river alignment, discharge, and sediment transport.

54. The construction of a single 2-ft-long dike into the 6-ft-wide channel of the model produced a scour hole in the channel bed at the nose of the dike and a sandbar downstream of the dike. This single dike did not produce any general degradation of the channel bed on the side opposite the dike. The vortex flow around the nose of the dike was capable of passing enough water through the scour hole so that there were no increases in velocities on the opposite bank. Because velocities on the opposite bank were not increased, the bed level on that side remained constant.

55. If left to evolve further, the bar would have continued to move into the area occupied by the small channel until the channel was filled by sand avalanching over the crest of the bar and into the side channel. The upper part of the small channel would close first, and thereafter closure would progress downstream. A calm backwater area would remain on the immediate lee side of the dike. After development, the level of the bar surface would be nearly equal to the flow stage that produced the bar.

56. The crest of the dike was constructed so that flood flows passed over the crest but low flows did not. The height of the dike had an important influence on the bar buildup. As the elevation of the crest was increased, more and more flow was forced to pass around the nose. Once the crest elevation was greater than the high-water level, the crest elevation had no more incremental effect on the flow. A dike with a higher crest level produced a shorter bar more rapidly than did the intermediate-level dike. Also, with the high dike and favorable depositional conditions upstream, the small channel filled more rapidly.

57. The effect of changing the flood level in the laboratory model was opposite to that of changing the dike crest levels. Lower

flood levels resulted in shorter bars and in a more rapidly filling small channel.

Dike field model

58. Adding another dike in the model on the same side of the channel downstream of the single dike changed the bar-building processes significantly. The initial effect was that much less flow entered the region between the two dikes and more flow passed into the contracted section. The second dike blocked the discharge of the small channel along the bank and less water and sediment entered the region between the dikes. The net result was that the bar between the dikes grew and moved inward much more slowly than when there was only a single dike.

59. As in the case of the single dike, the addition of vegetation to the bar helped to preserve the life of the side channel by stopping the movements of large amounts of bed sediments over the bar. Sedimentation still occurred in the backwater channel but at a significantly reduced rate.

60. The rates of sedimentation between the dikes were very rapid immediately after the dikes were built. The local scour at the nose of the dikes supplied the initial sediment; thereafter the bar-building materials were bed sediments transported by the river flows. When the bar became vegetated, sediment-laden bed currents no longer flowed over the bar. Sedimentation resulted from the settling out of the suspended sediments, the major portion of which was fine sand, from the slow-moving currents. The rate of sedimentation was significantly reduced.

61. Later, the side channel became isolated from the main channel by a dense growth of vegetation. Very little water flowed in the side channel because the path through the side channel was much more resistant to flow than the main channel. The side channel had become a backwater channel. The bed and banks of this channel and the surface of the island were covered with mud which deposited from the slack water that entered the side channel and covered the island during floods. The side channel slowly deteriorated in size due to the yearly deposition of mud; the rate of deposition is on the order of 1 to 5 in. per year in the Middle Mississippi.

62. In the absence of rare natural events, nearly all natural and man-induced side channels will completely fill with sediment unless something is done to maintain them. The rates of sedimentation vary greatly. Large chute channels can remain open for a century or may fill very rapidly depending on each situation. In most cases, side channels are transient features of the riverscape. They form and then are modified, and finally are filled by deposition.

63. In the model, the addition of a second dike was usually sufficient to cause a general degradation of the channel on the opposite side. The degradation caused a lowering of low-water levels, which could leave the small channel dry during periods of low flow.

64. To study the evolution of forms within a dike field, three model dikes were constructed in a straight stretch of laboratory river to be submerged during floods but exposed during low flow. The combination of flow over the dikes and blockage of the discharge in the side channel by the downstream dikes produced small bars and relatively large channels in the dike field.

65. In order to prolong the evolution of the dike field morphology, the elevation of the upstream dike crest was raised to a level above the flood level. The bars immediately enlarged and moved bankward, decreasing the size of the channel along the bank.

66. When the enlargement of the bar ceased before the channel along the bank filled, a notch was cut in the middle dike at the bankline. The notch permitted increased flow over the upstream bar, which in turn built rapidly bankward. There was no increase in flow over the downstream bar, but the channel below the notch filled with sediment carried from above. Soon the entire region in the dike field was filled with sediment.

67. The dike field performed admirably in terms of forming a deep, low-water main channel. The dike field narrowed the entire river channel except at stages above bank-full. The small channel and the surface of the bar were dry most of the time.

68. The material in the deposition areas came from the low-water channel and from the bed load carried by the river into the contracted

reach. Once the model dike field filled with sediment, the contraction had no measurable effect on sediment transport.

Notched-dike model

69. In the laboratory studies of the dike fields, the notching of the middle dike resulted in rapid sedimentation in the entire dike field. In subsequent tests, a notch was cut in the lower dike as well. With the additional notch, a side channel was obtained and maintained in the dike field.

70. The side channel produced by the configuration of a solid lead dike and two notched dikes consisted of a series of scour holes immediately downstream of the bankline terminal of each dike. Such scour holes would produce bankline failures along the side channel if the banklines were not stabilized. (In the model, the bankline was constructed with a sand-cement mix.)

71. During flood stages, the side channel was supplied a small amount of clear water flowing over the solid lead dike and a large amount that flowed around the nose of the lead dike, across the bar along the edge of the trees, across the crest of the second dike, and then into the side channel. During periods of low flow, the side channel was a slack-water area. During floods and intermediate flows, the side channel received sediments carried by the flow around the nose of the dike, but the amounts were not large. These sediments were transported on through the dike system. At low flows the side channel area received no sediments.

Summary

72. In summary, laboratory studies were successful in obtaining and maintaining side channels in dike fields under the following conditions:

- a. The bed elevation of the region where dikes were placed was below the low-water level. Otherwise, the side channels were dry at low flow.
- b. If there was flow at all stages in the side channel, the sediment transport capacity of the side channel could not be exceeded.

c. If the side channel was isolated from the main channel by large, heavily vegetated islands and there was a high, solid lead dike, the side channel would become a slack-water area, which would have a long life similar to that of Picayune Chute.

73. The outlook for obtaining and preserving side channels in the Middle Mississippi River by designing suitable structures in the dike fields is not good.

74. In the Middle Mississippi River, dike fields are usually placed in natural depositional areas such as the inside of bends. The bed elevations in these areas are greater than the low-water stages. Any side channels formed in such areas will be dry for a portion of the year.

75. In nearly all field situations, the inlet to the side channel formed by dike fields is located in such a position that the sediment transport capacity will be exceeded. Generally speaking, the life of such side channels will be increased if these intakes are closed soon after the side channels form.

76. It is possible to realign the river so that the intake to a side channel is in favorable position and alignment to obtain relatively sediment-free water. Realigning the river to form a favorable offtake is possible but would require massive structures to resist the forces of the main channel currents. An alternative would be to realign the entire river with standard dikes.

77. Notched dikes may help in extending the life of very few side channels. In general, the notched dike cannot be located in the proper position in the flow field. Also, bankline instability results at notches where large scour holes occur next to the bankline.

78. Because dike fields result in the lowering of the low- and intermediate-water stages, it is anticipated that groundwater levels in the aquifers connected to the river could be lowered. Also, some degradation of the tributary channels that flood while the main channel is at low stage should be anticipated.

PART III: TERRESTRIAL FLORA AND FAUNA OF THE UNPROTECTED FLOODPLAIN

79. The study by SIU integrated the results of all published and unpublished works dealing with the Mississippi River floodplain with those of present field research in order to characterize the biology of the project area. This was accomplished through extensive literature review, communication with knowledgeable persons, examinations of various floral and faunal collections, and field investigations in selected study areas containing representative plant communities of the unprotected floodplain. This part presents a summary of the SIU report.

Study Area

80. The study area was divided into nine major vegetation cover types: sand and mud flat, young bar, younger stand, older stand, early secondary succession, cultivated field, old field, water area, and developed land.* These cover types have many environmental conditions in common. Factors such as temperature, day length, precipitation, and general atmospheric conditions were nearly the same for all cover types; topography, soil properties, habitat diversity, available moisture and light, and the degree and frequency of inundation were not as similar.

81. Five study areas in Illinois and one area in Missouri were selected in the unprotected floodplain of the project area. Four Illinois sites were located at 50-mile intervals (river miles 162, 115, 60, and 6) for latitudinal definition. The fifth Illinois site, located at river mile 113, was on the Missouri side at Kaskaskia Island. Since the unprotected floodplain in Missouri was limited, one site was selected at river mile 64, approximately halfway between Kaskaskia Island and Cairo. Although the sites encompassed a north-south distance of

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* The term "cover type" can be equated with the term "community." However, "young bar," "younger stand," and "older stand" are not communities in the strict sense of the term due to intergradations; "water area" and "developed land" refer to physical aspects.

161 miles, there were no apparent differences due to latitude. Systematic sampling and general observations at six study sites revealed 145 species of plants in eight vegetation cover types.

Flora

82. The flora of the unprotected floodplain was largely composed of plants of two habitat types: semiaquatic and open-disturbed. Due to the swiftness of the river and the frequency of flooding, there were relatively few stable aquatic environments. Consequently, many plants normally expected in the floodplain were apparently rare or absent in the unprotected areas.

83. The disturbing effects of the river were reflected in the type of flora present in the project area. Generally, those plants found were common and likely to be found in many other low-lying and disturbed areas in Missouri and Illinois. Trumpet vine, grape, bur cucumber, balloon vine, catbrier, and other climbing plants appeared especially adapted to an environment frequently disrupted by flooding. The poorly developed soils, resulting from frequent flooding and continuous soil deposition, attract a weedy flora. Despite the open, pioneer nature of the unprotected floodplain, the flora does not contain an unusually high number of nonnative plants. Approximately 20 percent of the species were considered introduced. About 25 percent of the entire flora of Illinois were composed of nonnative taxa,[1] and 23 percent were nonnative in Missouri.[2]

84. The presence of four species of ground cherry (*Acalypha* spp.), eight of spurge (*Chamaesyce* spp.), and eight of smartweed (*Polygonum* spp.) was indicative of the instability of the unprotected floodplain. Highly productive and opportunistic species of willows, cottonwood, and composites (*Aster* spp., *Bidens* spp.) were characteristic of the area. The presence of other common weedy plants like poison ivy, pokeberry, cocklebur, and ragweed indicated the ubiquitous nature of many plants in the unprotected floodplain.

Description of plant communities

85. Young bars, which comprised 11.9 percent of the total acreage in the study area, supported the greatest diversity of plants; 77 species were observed. This community type lies, in most instances, between a primary successional community (sand and mud flat) and one that has gained a degree of stability (younger stand). Therefore, many species common to these closely associated types overlap with those species that are characteristic of young bars. Ten species were found unique to the young bar habitat.

86. Younger stands comprised 29.9 percent of the total acreage of the study area. This habitat type was next highest in diversity with 65 species observed. Younger stands formed the most common natural cover type in the unprotected floodplain but were the most difficult to delineate from other cover types. Younger stands were associated with the greatest number of other cover types and often bordered the main channel of the Mississippi River, especially on the cut-bank side, or were adjacent to backwater sloughs, cultivated fields, or old fields.

87. Early secondary succession (3.5 percent) with 51 species and old fields (0.9 percent) with 50 species appeared similar and had 22 species in common. However, the former type was most often located within established woodlands (older stands, younger stands, young bars), and the latter was associated with cultivated fields. Species diversity in both was enhanced by the availability of light and the relative lack of leaf litter.

88. Sand and mud flats form a distinct, easily recognized community. They were not extensive, composing only 2.2 percent of the total acreage. The open, pioneer nature of the flats provides a temporary but suitable habitat for a diversity of species that is deposited by frequent periods of high water. Twenty-seven species were reported from this cover type.

89. Older stands were the most mature cover type in the unprotected floodplain, making up 0.5 percent of the total. The largest older stand, located on Devil's Island, was sampled. Despite its

maturity, species diversity was considerably below that of less mature stands. Thirty-seven species were recorded, four of which were unique to this cover type. This decrease in species diversity with community development seems to conflict with some established trends in plant succession. According to Reference 3, there is a trend toward an increase in species diversity as succession advances from developmental (immature) to mature stages. The same principle, "as a simple community advances from a state of early succession to the richer communities of late succession species diversity increases," was found in Reference 4. The reason for this apparent conflict may lie in the fact that all unprotected floodplain vegetation types have many invading and opportunistic species that flourish in a disturbed and developing habitat. With a developing community, however, comes shade, leaf litter accumulation, and fewer disturbances. Most invading species are not favored by these factors since a lighted, open environment is an important requirement for germination and early growth. Furthermore, disturbance in the form of flooding is an important seed dispersal mechanism, of greater importance in less mature communities. Further development to a nonopportunistic community would no doubt bring greater species diversity.

90. Cultivated fields, which include actively and recently cropped land and fallow fields, formed the most extensive cover type (44.5 percent). Levees were also included in this cover type because they are mowed and are often used as pasture. Cultivated areas are not significant successional communities in the unprotected floodplain. The diversity and frequency of noncultivated species occurring in cropped or fallow fields are often seasonal and a function of farming activity. Thirty-five species, not including crop plants, were recorded from this habitat.

91. Water areas (5.5 percent) are highly unstable due to flushing in normal high water and the ephemeral nature of many backwater sloughs and depressions. No emergent species were recorded, and only one floating plant, duckweed, was observed in this cover type.

92. Developed land accounted for 1.2 percent of the total acreage. Due to potential loss or deterioration of equipment and buildings,

development of land in the unprotected floodplain is minimal.

93. Overall, 302 plant species in 66 families were recorded in the unprotected floodplain. Thirteen species of plants that are endangered or status unknown in Illinois or Missouri or both occur in the unprotected floodplain.

Successional trends

94. The recent history and developmental trends in unprotected floodplain vegetation in the Middle Mississippi River are given in References 5-8. The current absence of many of the tree species that were once recorded in the unprotected floodplain suggests that significant changes have occurred in vegetation structure and composition. Climatic conditions in the area have not changed significantly since 1856, when record-keeping in Illinois was begun. Changes in river vegetation have probably been brought about by man's logging and land-clearing activities, as well as by changes in river activity resulting from natural or man-manipulated causes.

95. Logging was common in the unprotected floodplain stands with the larger trees being used in veneer production for crates and boxes and the smaller trees for pulp.[8] During the period 1830-1926, the floodplain forests were heavily culled to supply fuel and building materials for settlers and fuel for steamboats, river towns, and industry.[8] Logging in the unprotected floodplain, especially for pulp, continues today.

96. Additionally, changes in riverflow caused by the present system of levees, dikes, and revetments are probably responsible for the demise of several species that were once a part of the unprotected floodplain. Prior to the establishment of levees, any high water overflowed the riverbanks and was distributed over a wide floodplain. The overflow was shallow and slow-moving; diminished by percolation and evaporation, the water remained a relatively short period of time. Except during the unusual floods or in surface depressions, the water may not have topped the root crown (root-stem conversion zone). "In general, it may be said that where the root crown was not permanently covered with impounded water, bottomland trees survived remarkably well."[9] The

hypothesis that high water in some bottomland areas exercises a selective killing of trees, thereby determining the makeup of the stands, was stated in Reference 10.

97. With the advent of levees, normal floodwater was confined in the river-to-levee area. There, water depth, duration of inundation, scouring action, and siltation were increased. Reproduction of less flood-tolerant trees was inhibited whereas trees more tolerant to flooding succeeded.

98. Succession in the present unprotected floodplain system begins in primary areas of sand and mud flats adjacent to the water's edge. These flats exercise little community control but rather are physically controlled by the river. Only rarely do any of these primary plants persist for more than one growing season. Those that do persist form the first line of permanent vegetation in the unprotected floodplain and begin a succession of community types that is increasingly internally controlled. Succession proceeds generally stepwise in a direction from the lowest elevation at the river's edge to the highest elevation near the levee. Disruptions of the successional process are common and largely the result of flooding, logging, and land clearing. Each progressive stage is characterized by increasing age, decreasing numbers of pioneer species, and, except for the most mature stands, by an increase in the land area occupied by the succeeding stage.

99. Most plant species in the unprotected floodplain are largely opportunistic, and even the most mature areas remain under the influence of the flooding river. Therefore, as mentioned earlier, with succession and community development comes an overall reduction in species diversity rather than the expected increase in diversity. Should the controlling effects of the river be reduced by a reduction in flood height and frequency and should the water table be lowered, succession would continue beyond the present disturbance climax. Species that were once a part of the unprotected floodplain would likely reappear. With time (perhaps geologic time), a stable floodplain system, not unlike those that were once associated with the ancient river, might evolve in some areas.

Fauna

100. A total of 53 species of mammals in 16 families was observed or expected to occur (based on previous sightings) in the project area.[11,12-15] Each cover type offers different microhabitats suitable for various mammalian species (e.g., beaver, muskrat, and river otter depend on the relatively still-water areas of some side channels and baylike areas below rock dikes).

101. The white-footed mouse, house mouse, and deer mouse were collected in all terrestrial habitats that were sampled, with the white-footed mouse being the most abundant species in each habitat type. Early secondary succession, younger stands, and cultivated fields showed good correlations between percent catch per cover type and percent trap-nights per cover type. On sand and mud flats sampled prior to flooding, 2.5 times the expected number of mammals were trapped, indicating a good food supply. The opposite effect was observed in young bars. Old-field vegetation also yielded more mammals than expected.

102. One hundred and seventy-four species and subspecies of birds were observed or expected to occur in the unprotected floodplain.[16-20] Of these 174, 76 species and subspecies were associated with older stands, 86 with younger stands, 48 with early secondary succession, 42 with young bars, 19 with sand and mud flats, 57 with water, 52 with old fields, 34 with cultivated fields, and 6 with developed land. Due to the similarity in vegetation in older and younger stands, the number of species using the areas was similar. A comparison of numbers of birds in early secondary succession, young bars, and old fields indicated that these types offer comparable forms of food and shelter.

103. Sand and mud flats attracted mostly waterfowl, shorebirds, and waders. Water attracted various species of swimming, diving, and wading birds in addition to several land species that hunt over the water. Fewer number of species found in cultivated fields reflected the lack of vegetative cover and seasonal use. Species occupying developed land were those which are tolerant of man.

104. Based upon previous sightings, a total of 86 species of reptiles and amphibians were expected to occur in the project area.[21-26] Amphibians are especially dependent on a source of water and are expected in high numbers in areas bordering water.

105. Exemplary species of many of the major insect orders inhabit the general region of the unprotected floodplain. Predominant groups present in the study area were numerous species of beetles (Coleoptera); butterflies and moths (Lepidoptera); terrestrial flies and mosquitoes (Diptera); grasshoppers, crickets, etc. (Orthoptera); terrestrial bugs (Hemiptera); and ants, bees, and wasps (Hymenoptea). Also present were noninsect groups of spiders, ticks, and mites (class Arachnida).

106. Overall, 16 species of mammals, 24 species of birds, and 19 species of reptiles and amphibians that occur in the unprotected floodplain are listed as rare, endangered, or status unknown in Missouri, Illinois, or both. Included were 4 species of national concern (rare and endangered or status unknown). The status of each species was based on lists given in References 27 and 28.

PART IV: AQUATIC FLORA AND FAUNA

107. A study of three side channels and adjacent river border areas made by Ragland of the MDC[29] and a study by WES within the same reach of the river but including 23 side channels and four river border areas[30] are summarized in this section. These studies were made to evaluate the importance of side channels and river border areas in the Middle Mississippi River as spawning, nursery, and feeding habitat for fish and to document the diversity of aquatic organisms.

Sampling Programs

108. Ragland[29] reported on a five-season study conducted by the MDC during 1972-1973 on the Osborne, Fort Chartres, and Liberty side channels and on their adjacent river border areas. Phytoplankton, zooplankton, benthic macroinvertebrates, and fish were collected and statistically analyzed.

109. A study team from WES made collections during three sampling periods (June-July 1972, August-September 1972, and July 1973) for aquatic biota from 23 side channels. Samples included benthic macroinvertebrates, phytoplankton, and zooplankton collected during the first two sampling periods plus fish collected during the latter two sampling periods. During the third sampling period, phytoplankton, zooplankton, and benthic macroinvertebrates were sampled at only 13 of the side channels. Results from fish seining were reported for four river border areas during the latter two sampling periods, and benthic macroinvertebrates, phytoplankton, and zooplankton were collected from the same four river border areas during the third sampling period.

110. Two main aquatic habitat types of the Middle Mississippi River, river border areas, and side channels were investigated and found to contain various assemblages of flora and fauna. River border areas are those areas between the 9-ft navigational channel and the main riverbank. "Side channel" is an all-inclusive term for those departures from the main river channel in which there is water flow during normal river stages.

Results of Inventories

Phytoplankton

111. Both river border areas and side channels are subject to fluctuating water levels, and turbidity levels are characteristically high. High turbidity, shifting substrate, and fluctuating water levels prevent the growth of rooted aquatic macrophytes within the river proper and most areas within the side channels. As a result, phytoplankton assemblages probably account for most of the primary production that occurs. Ragland[29] observed that secchi disc transparency was almost 50 percent higher in the Osborne, Fort Chartres, and Liberty side channels than in adjacent river border areas. Since primary production is a function of available light energy, greater numbers of phytoplankton were expected in the side channels. However, no significant differences in phytoplankton numbers were detected in the study by Ragland. The study by WES[30] for different side channels and river border areas showed phytoplankton populations to be at least twice as large in two side channels and only 50 percent as large in one side channel than in adjacent river border areas during the summer of 1973. Little difference was observed in phytoplankton populations in a comparison between another side channel and its adjacent river border area.

112. The WES study showed the Chrysophyta to be the dominant phytoplankton group in most of the 23 side channels and four river border areas during the study period 1972-1973 (Figures 2-5). This trend has been observed for other large turbid rivers.[31] Lowest numbers were observed for Cryptophyta during the WES study. In contrast, Ragland[29] found Chlorophyta to be the most dominant among all other phytoplankton groups and Cyanophyta were found in minimal numbers.

Zooplankton

113. Ragland found that zooplankton occurred in greater numbers in three side channels than in adjacent main channel borders. Rotifers were found to be dominant in side channels, and copepods were dominant in river border areas. Among four of the side channels and adjacent river border areas studied by WES[30] during the summer of 1973,

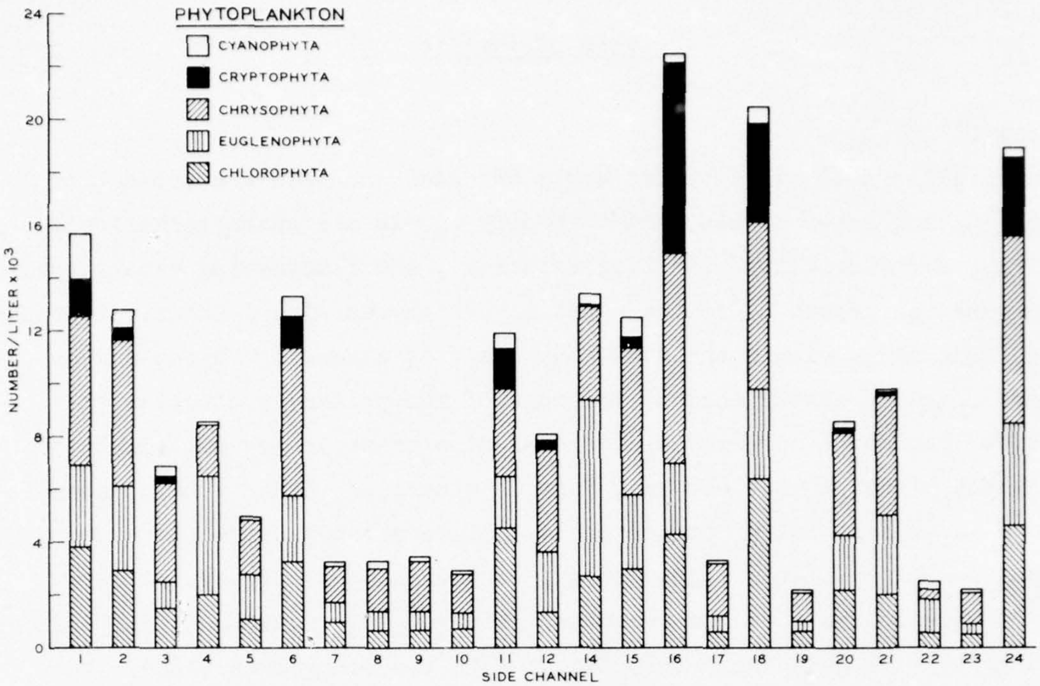

Figure 2. Phytoplankton collected during sampling period I (19 June-1 July 1972), in side channel areas

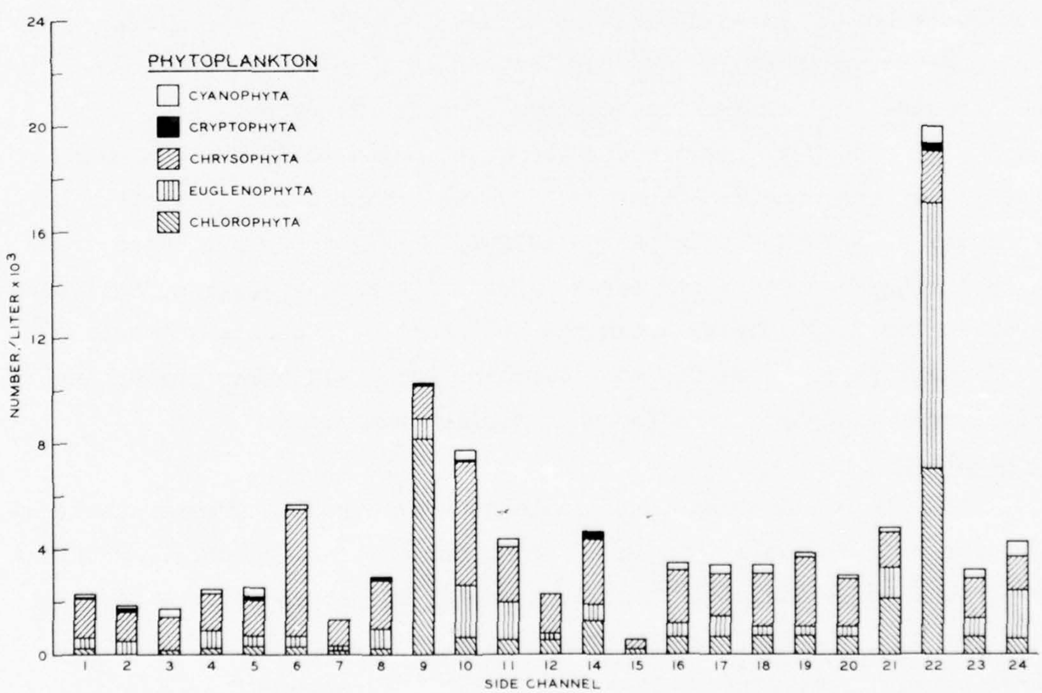

Figure 3. Phytoplankton collected during sampling period II (21 August-11 September 1972), in side channel areas

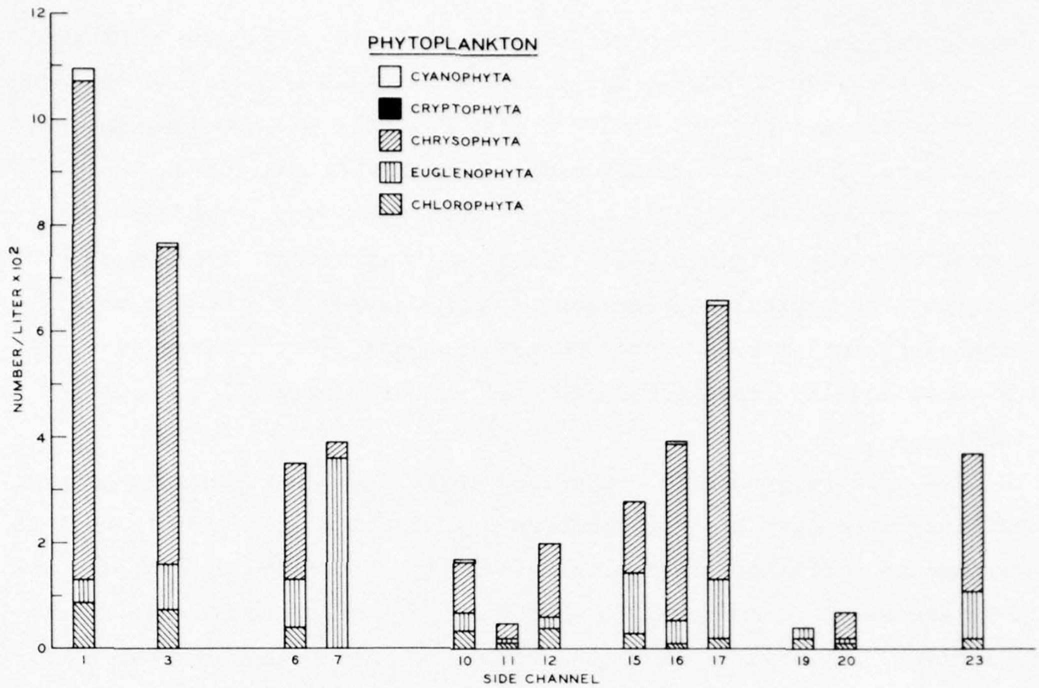

Figure 4. Phytoplankton collected during sampling period III (10-28 July 1973), in side channel areas

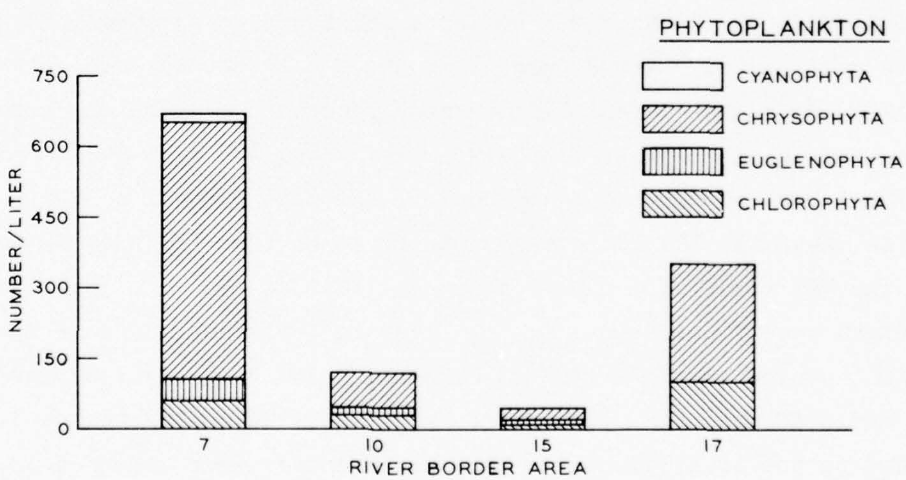

Figure 5. Phytoplankton collected during sampling period III (10-28 July 1973), in river border areas

Copepoda was dominant in two of the side channels; Cladocera dominated in one of the side channels; and Protozoa was most abundant in one other side channel. Among river border areas, Protozoa was the dominant zooplankter. However, when all side channels were considered during the study period (1972-1973), rotifers were found to be the dominant zooplankton group (Figures 6-9). This is in agreement with Hynes, who noted that the typical zooplankton of large rivers is nearly always dominated by rotifers.[31] Copepoda and Protozoa, next in abundance, were about equally represented in total numbers among all 23 side channels.

114. It is generally recognized that lentic environments provide conditions more suitable for plankton reproduction and growth than lotic environments. Plankton that originate in the pools above St. Louis very likely are swept downriver into the upper portion of the Middle Mississippi River. In this reach of the river, the side channels most nearly approximate lentic conditions found in the pools above St. Louis. These areas probably contribute significantly to the plankton populations occurring in the river proper.

Benthos

115. Ragland[29] found oligochaetes to compose only 3 percent of the total benthos in the river border areas and side channels. Aquatic insects contributed over 95 percent of the total benthos. In contrast, the WES study[30] showed that oligochaetes comprised a much larger percent of the total benthos (Figures 10-12). While Ragland also indicated that total benthos were more abundant in the main channel border than in the side channels, WES found the opposite to be true (Figures 10 and 11). The WES study also showed that of a total of 60 taxa collected, only eight were found solely in the river border areas; 29 were found only in the side channels; and 23 were common to both river border areas and side channels. The differences observed in the two studies were due to the fact that different side channels were compared and that different sampling methods were used. Artificial substrate samplers used by Ragland were left in the water for 6-7 weeks in both habitats to allow drift organisms to colonize the substrate contained

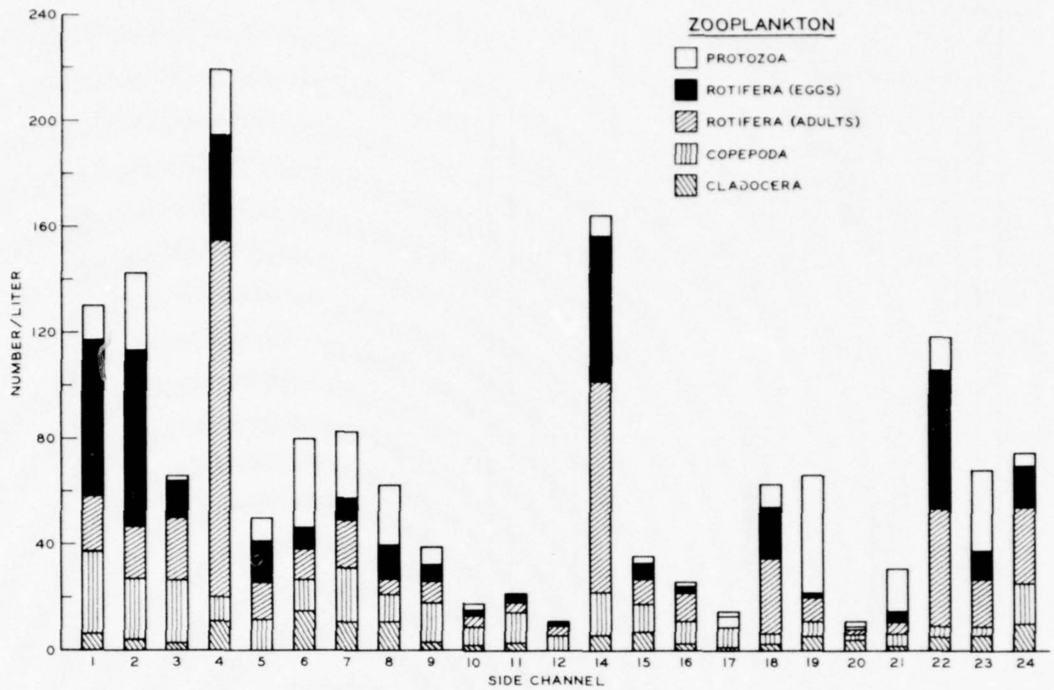

Figure 6. Zooplankton collected during sampling period I (19 June-1 July 1972), in side channel areas

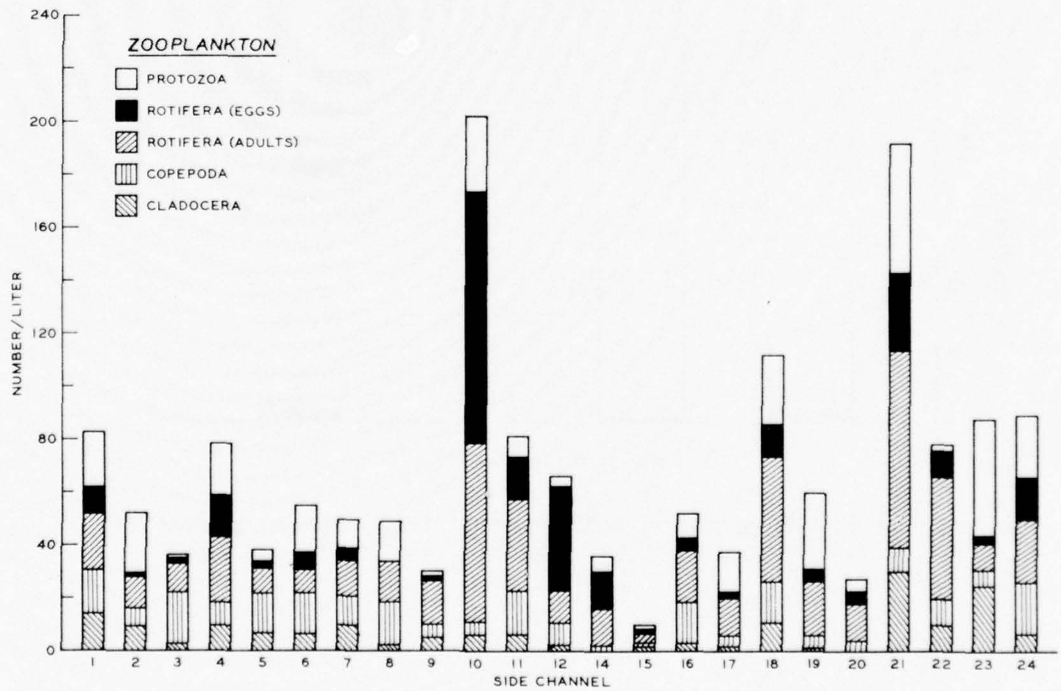

Figure 7. Zooplankton collected during sampling period II (21 August-11 September 1972), in side channel areas

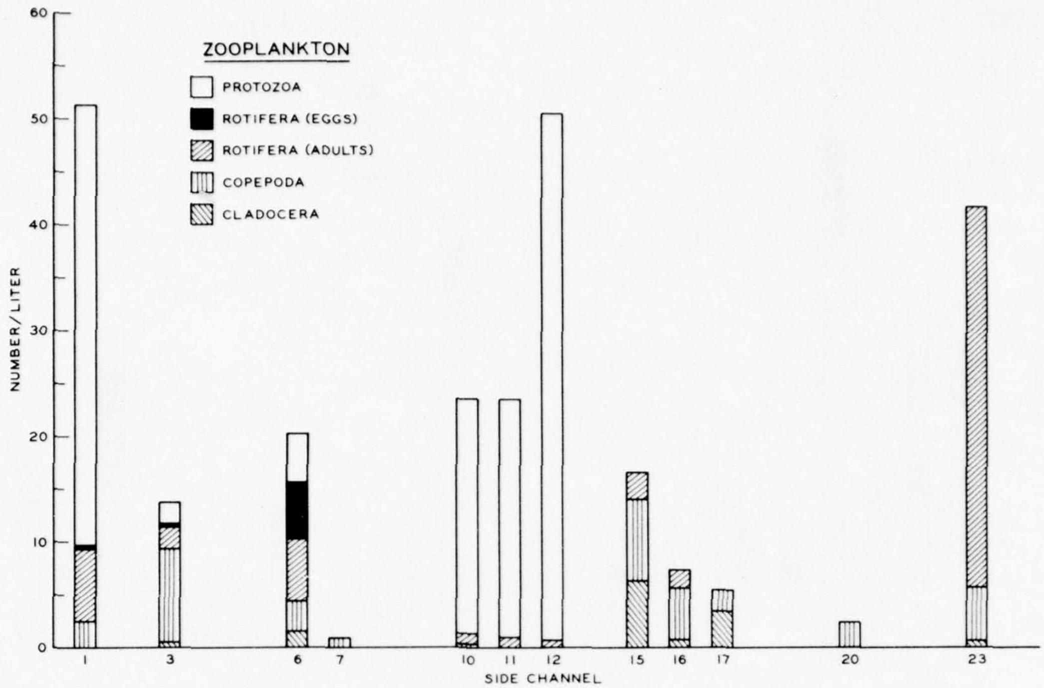

Figure 8. Zooplankton collected during sampling period III (10-28 July 1973), in side channel areas

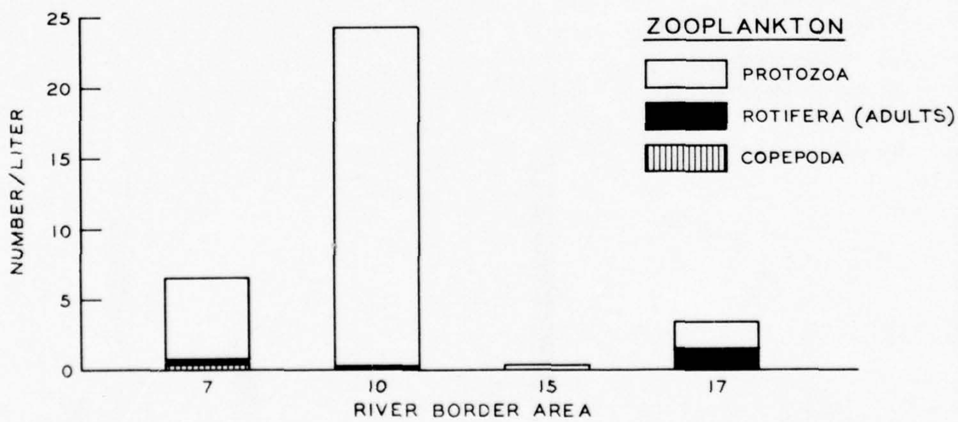

Figure 9. Zooplankton collected during sampling period III (10-28 July 1973), in river border areas

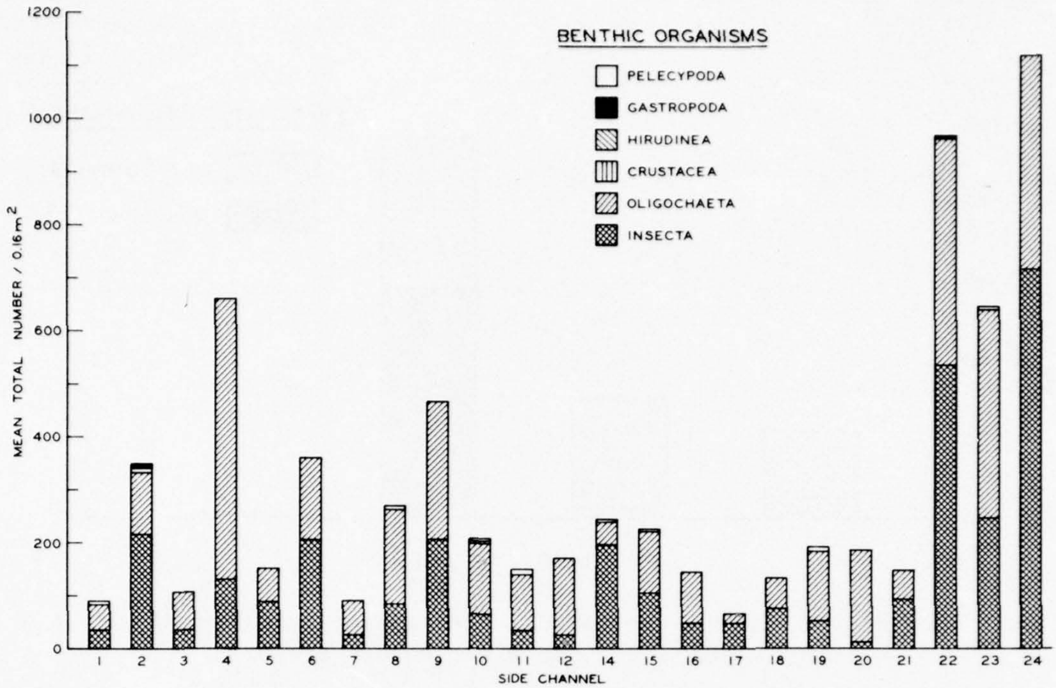

Figure 10. Benthic invertebrates collected during sampling period II (21 August-11 September 1972), in side channel areas

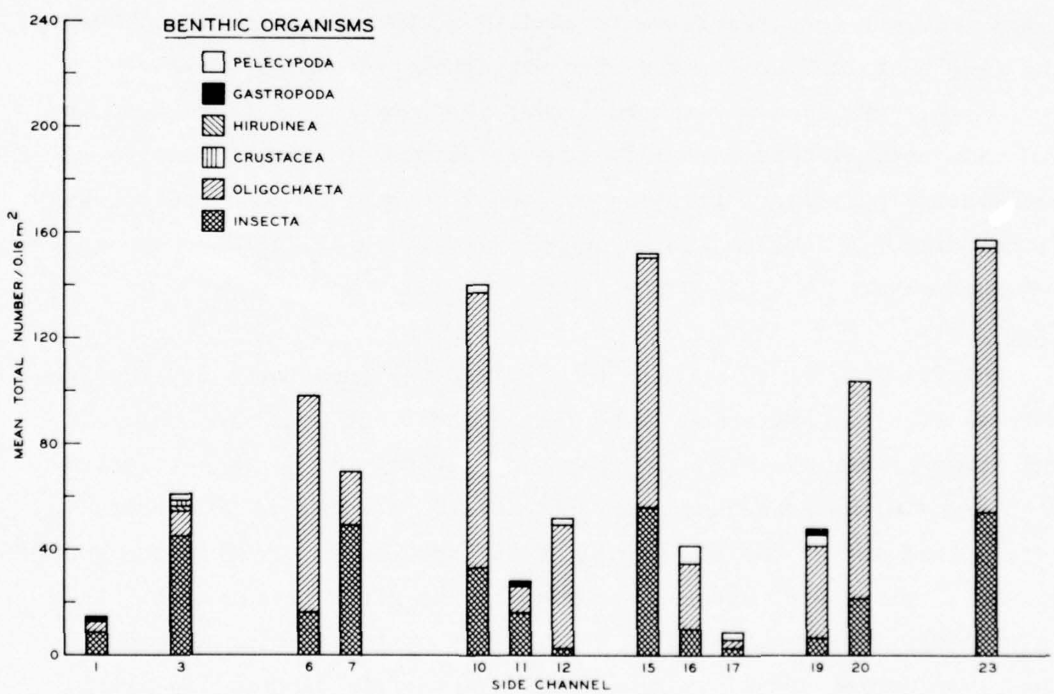

Figure 11. Benthic invertebrates collected during sampling period III (10-28 July 1973), in side channel areas

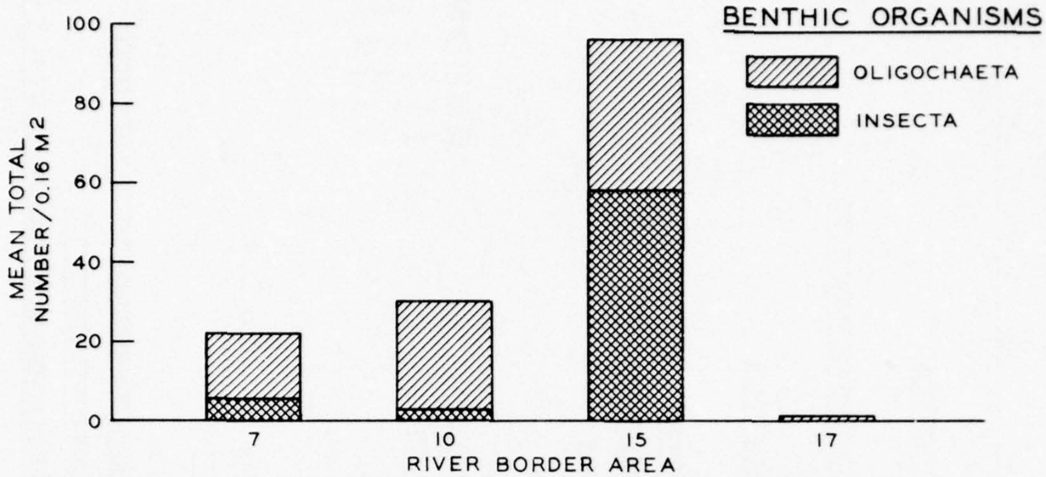

Figure 12. Benthic invertebrates collected during sampling period III (10-28 July 1973), in river border areas

in the sampler. The successful colonizers of such samplers generally are anatomically adapted for clinging. The collection of certain pollution-tolerant or pollution-sensitive species on artificial samplers helps indicate the overall water quality at the sampling site; however, the true benthic fauna at the site may not be adequately measured.

116. WES used a Petersen dredge for sampling in side channels and main channel borders. This type of sampler is also effective in the Mississippi River; it does not depend on benthic colonization but rather directly samples the organisms already established in the bottom sediments.

Fish

117. WES, in an attempt to evaluate the importance of side channels as fish nursery areas, made fish collections from side channels and river border areas during the study period. A 25- by 4-ft seine with 3/16-in. mesh was used for collecting. A total of 52 species were netted during the study; all of the species occurred in the side channel, but only 29 species occurred in the river border area. This is probably the result of the inefficiency of the seining method in the river border areas. Ragland, using a variety of sampling gear,

collected a total of 54 species; of this total, 8 fish species found in the side channels were not found in river border areas and vice versa.

118. The WES study indicated, on the basis of increased numbers of young-of-year fish between sampling periods II and III, that fish spawning was more successful during period III (Figures 13 and 14). High-water conditions during the spring of 1973 possibly increased the amount of habitat suitable for spawning.

119. The frequency of occurrence of sport, forage, commercial, and predator fish species in 23 side channels and 4 river border areas was analyzed. Thirteen species of sport fish were collected from side channels during sampling period II (Figure 15). Among all side channels, bluegill, black crappie, and white bass occurred in 22, 14, and 9 side channels, respectively. During the second sampling period, 16 species of sport fish were collected from side channels. White bass occurred in 21 side channels; white and black crappie occurred in 19 and 16 side channels, respectively; and channel catfish occurred in 18 side channels.

120. Twenty-two species of forage fish were collected from side

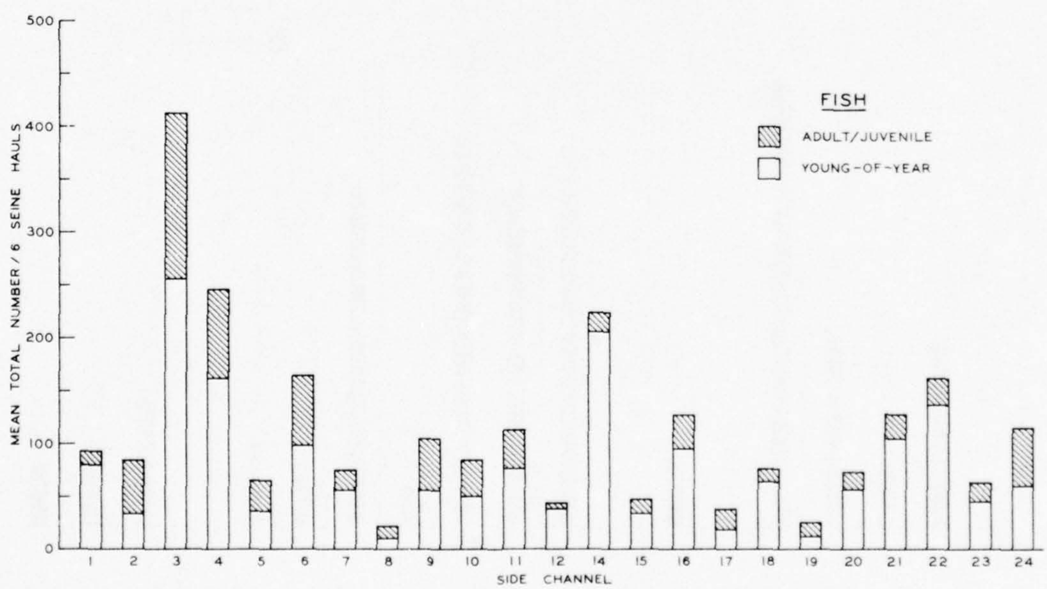

Figure 13. Adult/juvenile and young-of-year fish collected during sampling period II (21 August-11 September 1972), in side channel areas

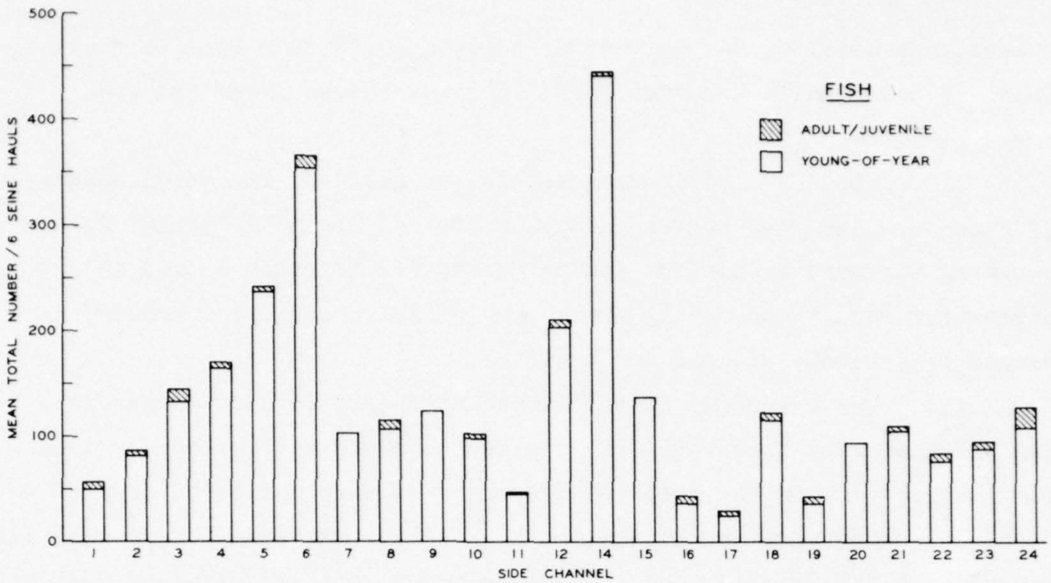

Figure 14. Adult/juvenile and young-of-year fish collected during sampling period III (10-28 July 1973), in side channel areas

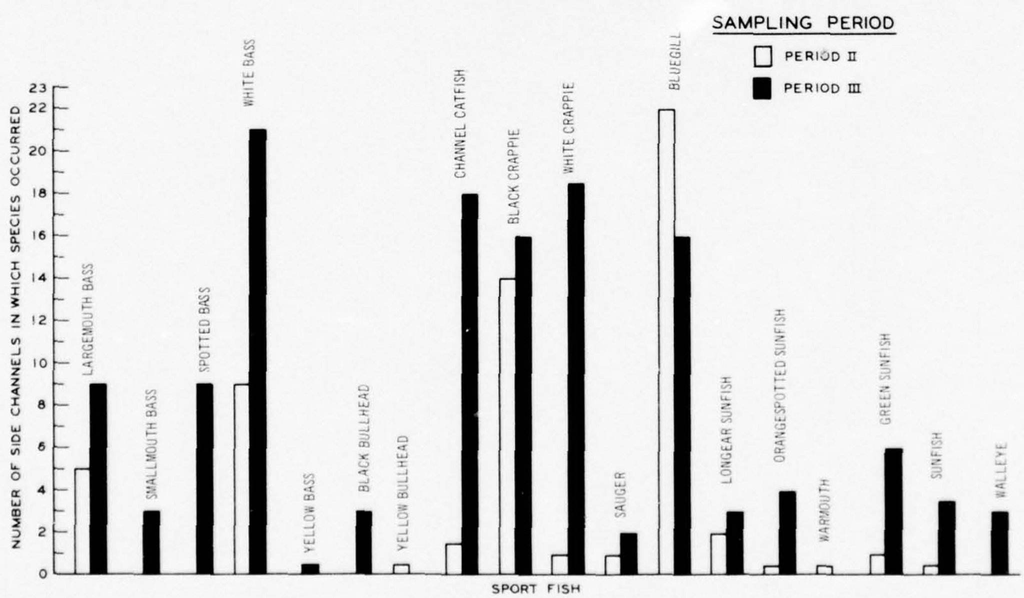

Figure 15. Frequency of occurrence of sport fish among side channels during sampling periods II (21 August-11 September 1972) and III (10-28 July 1973)

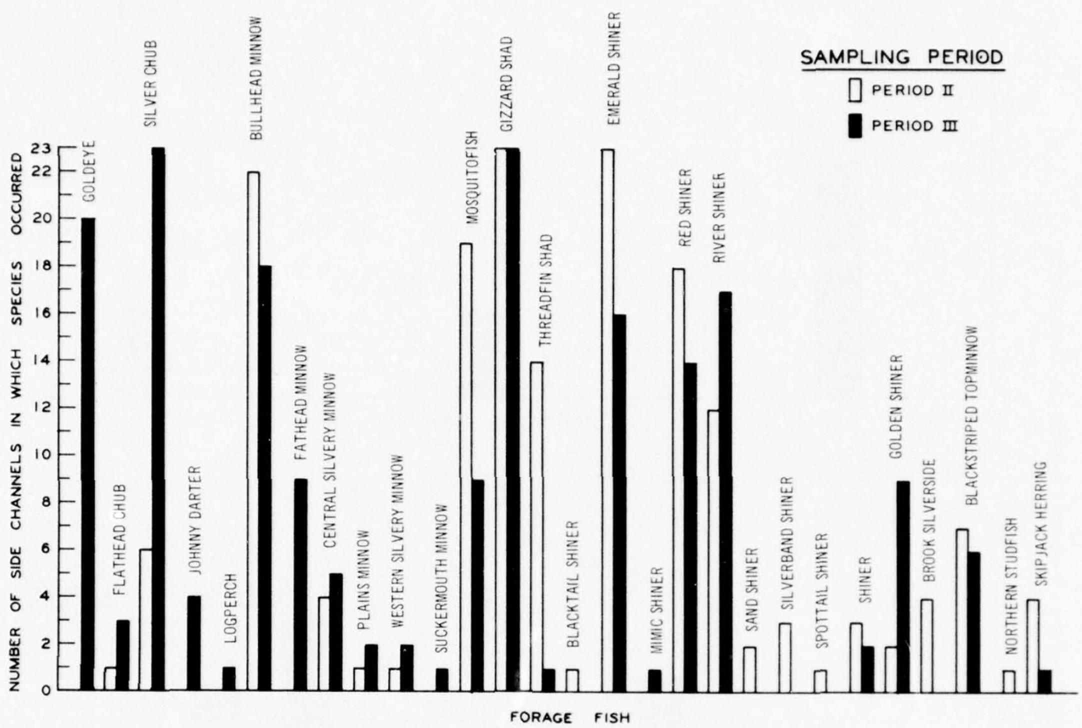

Figure 16. Frequency of occurrence of forage fish among side channels during sampling periods II (21 August-11 September 1972) and III (10-28 July 1973)

channels during both sampling periods (Figure 16). Gizzard shad and emerald shiners occurred in all 23 side channels, and bullhead minnows occurred in 22 of the side channels during period II. During sampling period III, gizzard shad and silver chubs were collected in all side channels. Goldeye occurred in 20 side channels; bullhead minnows occurred in 18; and red shiners occurred in 17 side channels. As a group, shiners generally occurred in fewer side channels during period III.

121. Three species of gar were the only predator fish collected from side channels during both sampling periods (Figure 17a).

122. Only five species of commercial fish occurred in side channels during the combined sampling periods (Figure 17b). Freshwater drum and smallmouth buffalo occurred in more side channels than did bigmouth buffalo, carp, and river carpsucker, which were collected in

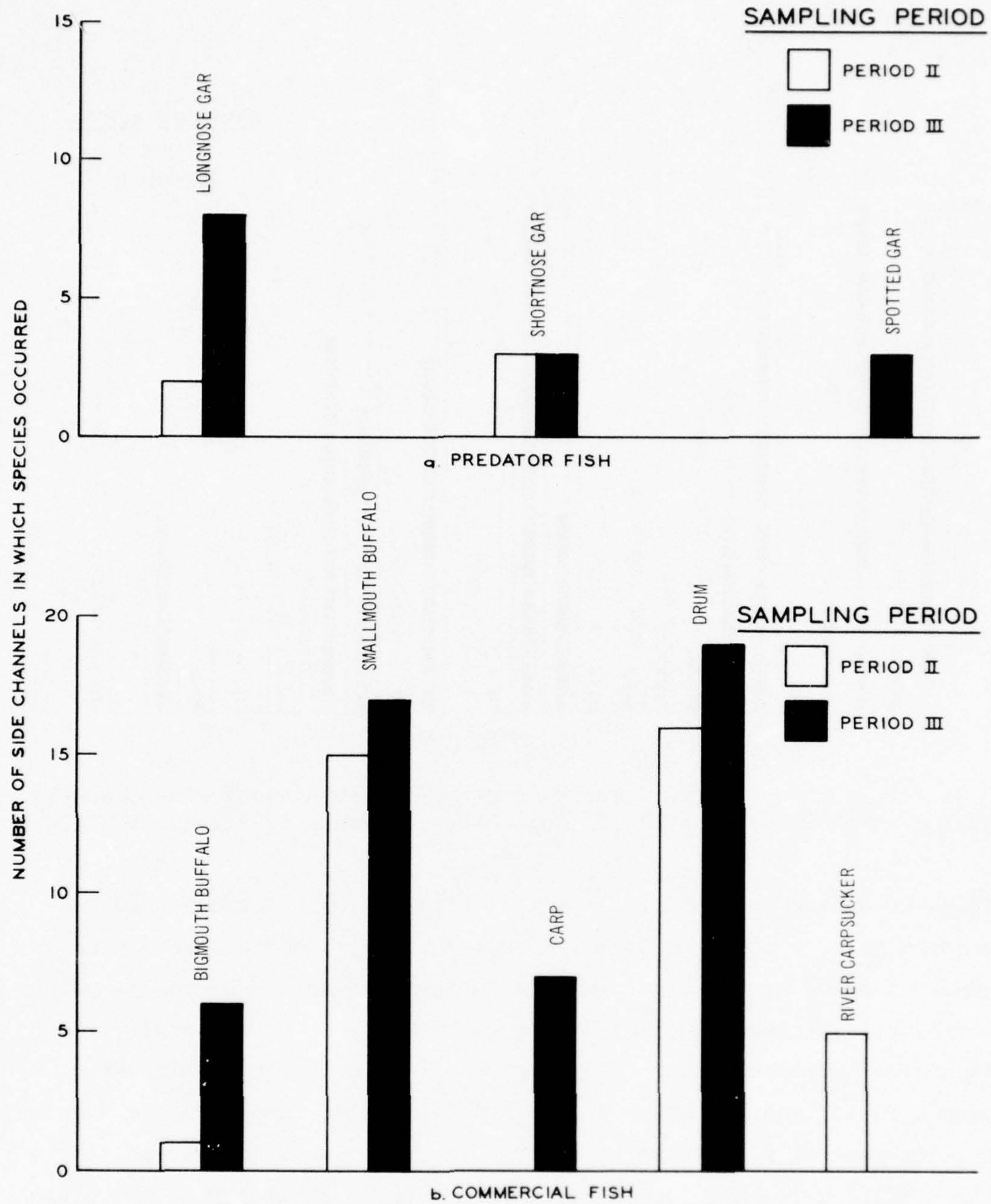

Figure 17. Frequency of occurrence for predator fish and commercial fish among side channels during sampling periods II (21 August-11 September 1972) and III (10-28 July 1973)

about the same number of side channels. With one exception, commercial fish species occurred in more side channels during sampling period III than during sampling period II. High-water conditions during period III possibly made side channels more accessible to certain fish species.

123. In the four river border areas sampled during the study, no sport fish were collected during period II (Figure 18). Of the eight species collected during sampling period III, white crappie and white bass, respectively, occurred in three and four of the areas sampled.

124. Fewer commercial fish were collected from river border areas than from side channels. Freshwater drum and carp, respectively, were collected in two and one of the river border areas during period III; smallmouth buffalo were collected in only one river border area during period II. The low number of commercial fish taxa observed in these areas was probably due to poorer sampling efficiency in river border areas.

125. Although not shown graphically, spotted gar was the only predator fish collected from river border areas during period III. No predator fish were collected during period II.

126. Ten forage fish species were collected from the four river border areas during sampling period III (Figure 19). Gizzard shad, silver chub, goldeye, and river shiner occurred in two or more of the areas sampled. Only four species of forage fish were collected from the corresponding river border areas during period II. All four species--red shiner, gizzard shad, bullhead minnow, and emerald shiner--occurred in at least two of the four river border areas.

127. While it is recognized that high water had considerable influence on the numbers and kinds of fish collected during period III, an attempt was made to compare side channels and river border areas during both sampling periods. Total number of fish and numbers of fish of each category from both areas are best compared by sampling period. Based on total numbers, more fish were collected at side channels 7, 10, 15, and 17 than at adjacent river border areas during period II (Figures 20 and 21). Also, with the exception of location 17, side channels were represented by a greater number of fish categories than river border areas. Only forage fish were found in river border areas 7, 10, and 15 during period II.

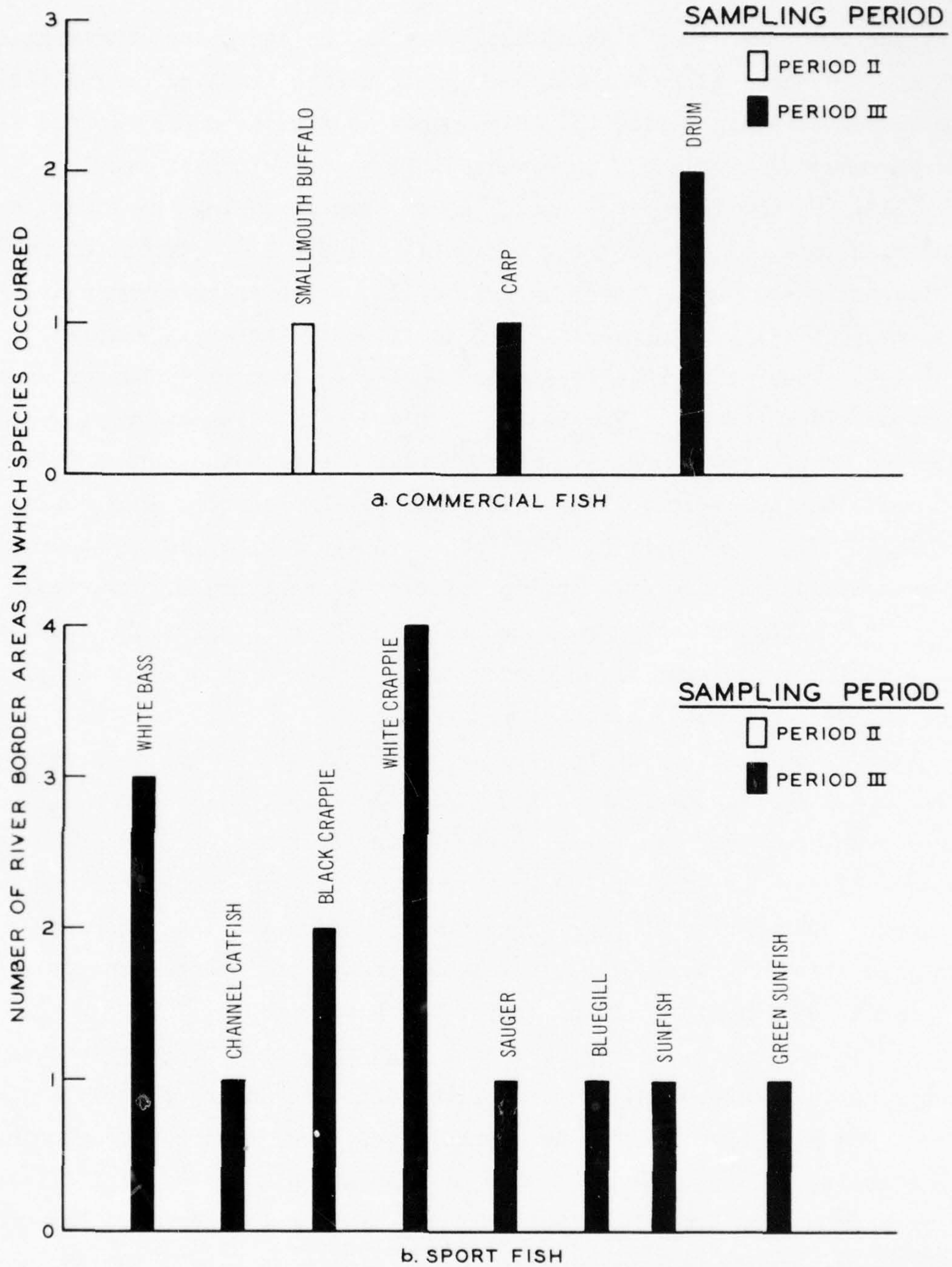

Figure 18. Frequency of occurrence for commercial fish and sport fish among river border areas for sampling periods II (21 August-11 September 1972) and III (10-28 July 1973)

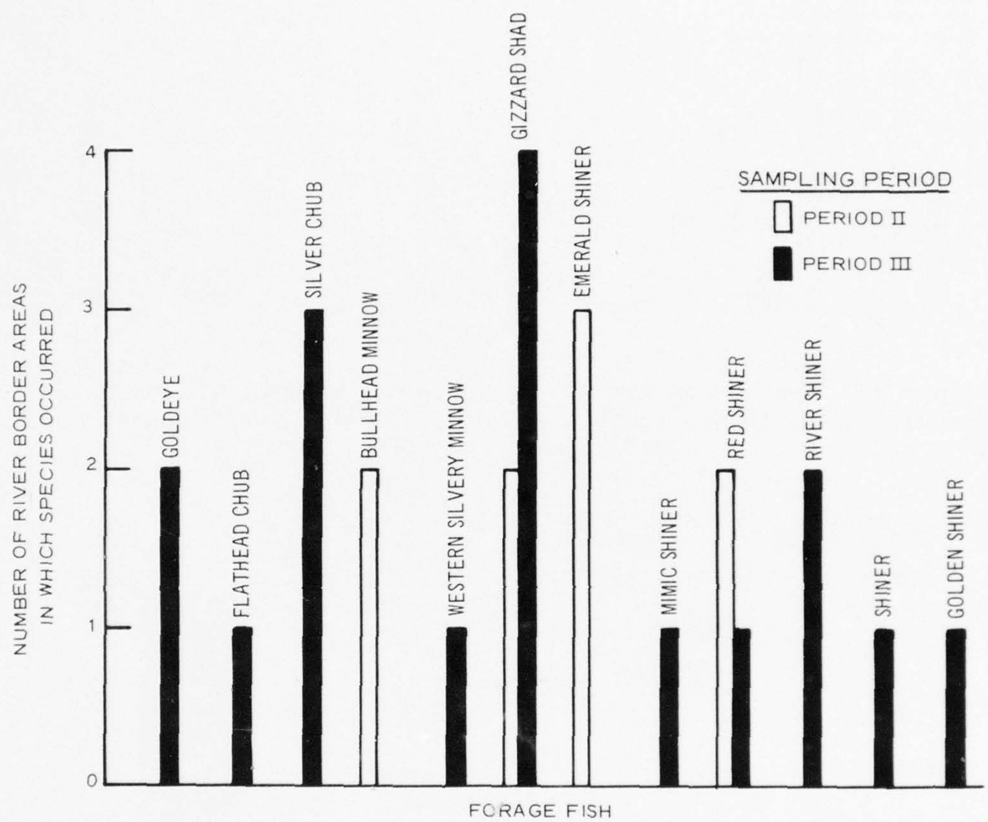

Figure 19. Frequency of occurrence for forage fish among river border areas during sampling periods II (21 August-11 September 1972) and III (10-28 July 1973)

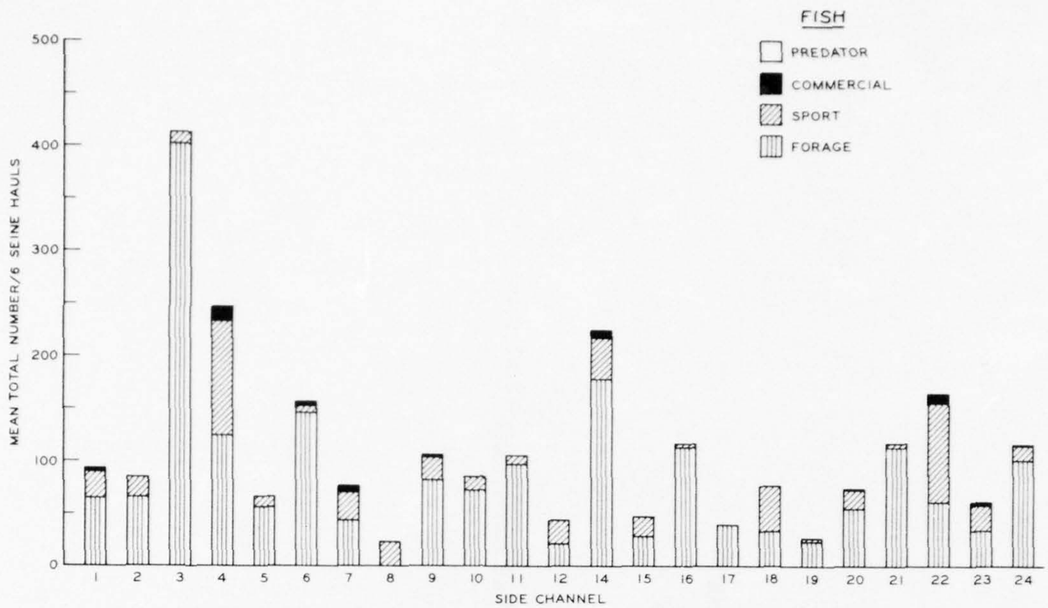

Figure 20. Mean total numbers of predator, commercial, sport, and forage fish collected from side channels during sampling period II (21 August-11 September 1972)

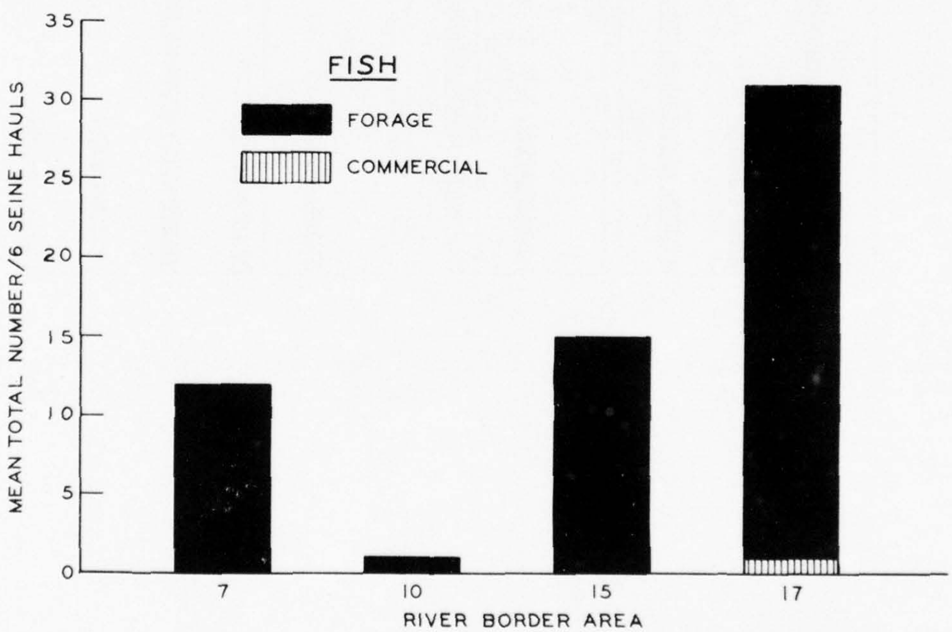

Figure 21. Mean total numbers of forage and commercial fish collected from river border areas during sampling period II (21 August-11 September 1972)

128. During sampling period III, which was characterized by high water, there were less differences observed between side channels and the adjacent river border area (Figures 22 and 23). Total numbers of fish collected were similar at each side channel and adjacent river border area, including location 17. These similarities are probably best explained in that during this sampling period, side channels and river border were less distinguishable, because of the homogenizing effect of high water.

129. Analysis of fish data collected during 1972, a year characterized by normal flow, indicated that the desirable sport and commercial young-of-year and adult/juvenile fish occurred in side channels. The increase in total number of fish during 1973 may indicate the importance of occasional flooding, which increases the amount of area inundated by shallow water and thereby provides more area for the successful reproduction of fish.

130. Fish collections made by Ragland using a variety of sampling gear also indicate the importance of side channels for both young-of-year and adult/juvenile fish. Minnows and small fish were nearly six times more abundant in seine collections from the side channels than in main channel borders. For the more abundant fish species, electrofishing and netting captured significantly more carp, bluegill, shortnose gar, black crappie, bigmouth buffalo, white crappie, and bowfin in the side channels than in adjacent main channel borders. Largemouth bass were found only in the side channels. Significantly greater numbers of freshwater drum, sauger, and flathead catfish were observed in main channel borders.

131. Both studies showed in varying degrees that side channels were different ecosystems from the main channel. The side channels were shown to contain numerous fish and food chain components that were not found in the river border area (Table 1).

132. The WES study evaluated more side channels than river border areas; however, the river border areas sampled were considered representative of that reach of the river. Ragland's study showed more equal representation of numbers of taxa for both side channels and river

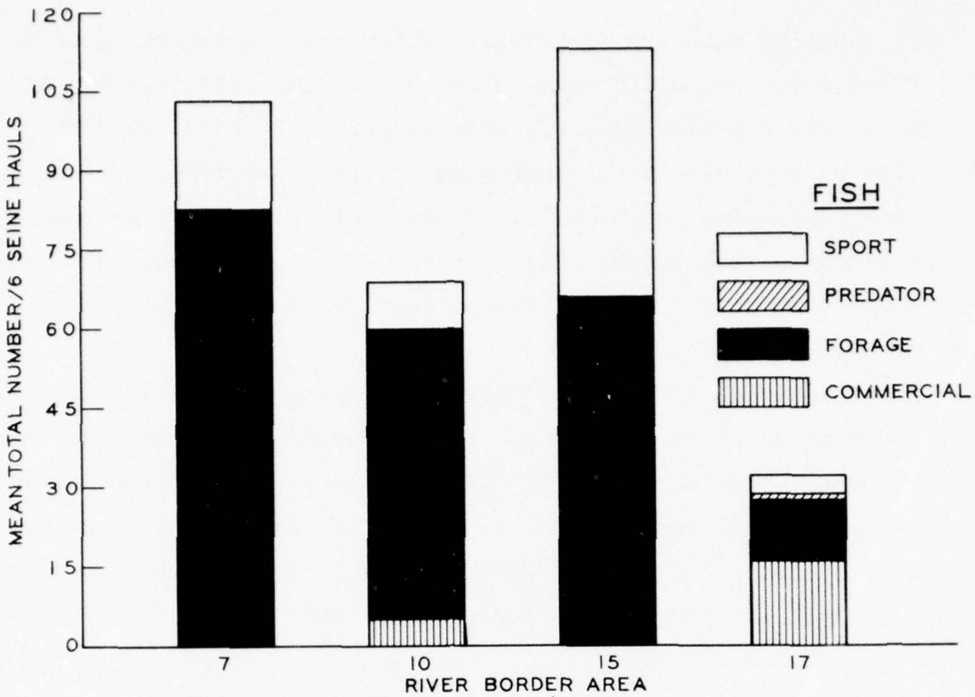

Figure 22. Mean total numbers of sport, predator, forage, and commercial fish collected from river border areas during sampling period III (10-28 July 1973)

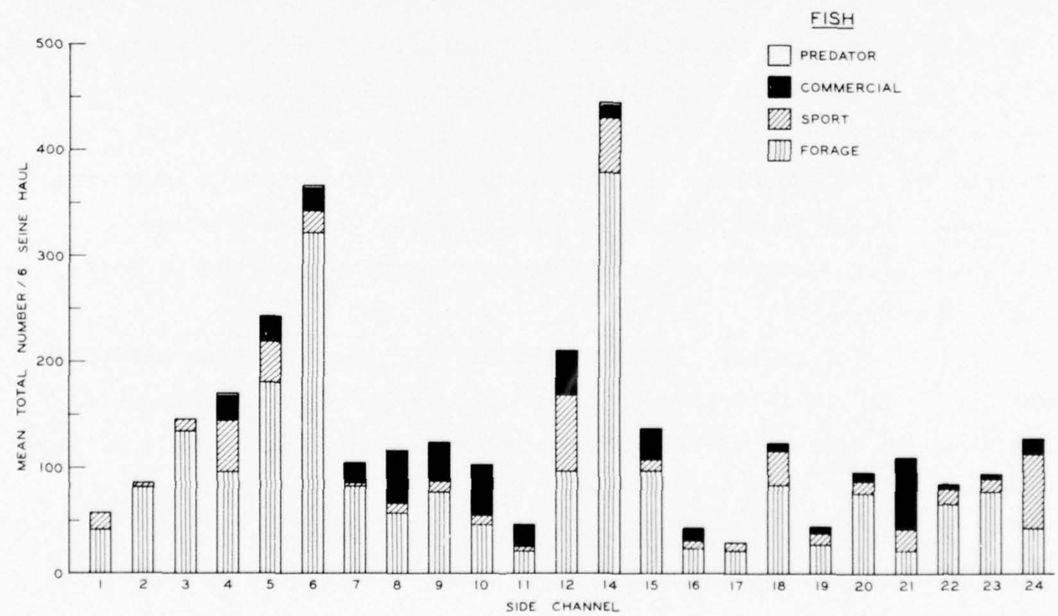

Figure 23. Mean total numbers of predator, commercial, sport, and forage fish collected from side channel areas during sampling period III (10-28 July 1973)

border areas; however, 50 taxa of aquatic organisms overall were found in the side channels that were not found in the river border areas. The additional diversity observed among side channels indicates the value of these side channels as aquatic habitats.

133. No rare or endangered aquatic organisms were collected in the study area.

134. Note to reader: Data from Parts II through IV were used in preparation of the remainder of this report; information from Parts II through IV is repeated as necessary in the later parts so that the later parts can be used by SLD in preparation of an Environmental Impact Statement.

PART V: STATISTICAL ANALYSES

135. The WES study included collection of morphometric, physical, chemical, and biological data from 23 side channels in the Middle Mississippi River during 1972-1973. Similar information, except for morphometric data, was also collected from adjacent river border areas. All data were transferred to magnetic tape for manipulation purposes and for subsequent statistical analyses. Analyses of variance (AOV) and t-tests[32] were performed to test for differences among stations and side channels during each sampling period and to test for differences between side channels and river border areas for selected variables. Additionally, AOV's were used to test the relationship of benthic organisms to substrate classification and depth among side channels for sampling periods II and III. Correlation and multiple regression analyses were also performed. A Fortran IV computer program was written to generate two-way tables with marginal means of location (side channel and river border areas) by station observations for each sampling period. The marginal means by location and sampling period for each variable are given in Appendix A.

Analyses of Variance (AOV)

136. Five different AOV's were computed using the data from side channels. The first three AOV's were calculated for each variable within each of the three sampling periods. All observed values for biological variables tested in these AOV's were analyzed similarly using the applicable log or square root transformation of the observed data. Since in almost every instance the results of the AOV's using transformed values were identical with the analyses using untransformed values, only the untransformed data and analyses are presented and discussed. The fourth and fifth AOV's, which deal with the relationship of benthic organisms to substrate classification and depth, respectively, were calculated using the data combined from all three sampling periods.

Differences among side channels (one-way AOV)

137. First, each variable was analyzed to detect differences among side channels. Station observations within side channels were averaged to produce the marginal side channel means for the data collected. A one-way AOV was calculated with the three station observations within each side channel being considered as replications for the side channel.

138. The results of the F-tests for each of the AOV's calculated are presented in Table 2. A significant F-test indicates only that there were differences among side channel means. In order to locate where differences occurred, an approximate least significant difference (LSD) was calculated,[32] and any two means that were found to differ by more than the calculated LSD were then considered significantly different ($P < 0.05$). The LSD is referred to as approximate since the average number of side channel replications was used in its calculations. It is important to realize that the LSD is to be applied only when the F-value obtained in the AOV is significant.

139. For the majority of the variables analyzed, the F-tests in the AOV's for side channel differences (Table 2) were significant in all three sampling periods, which indicates substantial variation among side channels as a whole. During sampling period I, 96 percent of the variables tested were significant. Of the variables tested during sampling periods II and III, 61 percent and 58 percent, respectively, were significant. It might be expected that the fewer significant differences among side channels for sampling periods II and III might be due to more data variability as a result of high water or other environmental conditions. However, for each variable that was observed and analyzed during all three sampling periods, the coefficient of variation within each sampling period either decreased or remained fairly constant over time. This indicates that side channels became more similar for the variables tested. In fact, it is possible that high-water conditions, especially during sampling period III, had a homogenizing effect on many side channels, thus explaining the reduced number

of significant differences among side channels.

140. Among the variables tested during sampling period II, more differences among side channels occurred for physicochemical characteristics and benthic organisms than for other classes of characteristics. During sampling period III, more differences among side channels were again observed for physicochemical variables; differences related to benthic organisms and other biological variables were fewer than in period II.

Differences among stations (one-way AOV)

141. A one-way AOV was calculated to detect differences in the overall or marginal means for comparative stations. In all side channels, sta 1 was located near the primary exit, sta 3 was located near the primary entrance, and sta 2 was located midway between sta 1 and 3. Since station locations were geographically similar in all side channels, it was of interest to determine if any differences could be detected in the overall station means. Hence, a one-way AOV was computed where the observations over side channels were considered as replication for the station. Since so few significant variables indicative of station mean differences were detected by the F-test in these analyses, the results are not presented in tabular form.

142. The overall station mean did not differ for one of the following two reasons: either there were no actual differences for the variables studied or there were no consistent differences among stations from one side channel to the next. The latter reason appears to be the more meaningful one, since the observed differences among station means were very large. The ranges of observed values for station means within side channels are not presented in this report but are available in Tables 6-32 of Reference 30.

143. The only variables for which significant station differences were detected by the F-test in the one-way AOV were pH and water temperature during sampling period I. Apparently, consistent differences among stations within side channels occurred for these physicochemical variables.

Differences within each
<u>sampling period (two-way AOV)</u>

144. A third AOV was calculated for each variable within each sampling period. This analysis was a two-way AOV in which both side channel mean differences and station mean differences were estimated and tested simultaneously. One can think of this analysis as a test for (a) differences among side channel means after the mean differences for stations have been accounted for and (b) differences among station means after the differences for side channel means have been accounted for.

145. The two-way AOV is a more sensitive analysis than the one-way AOV except when the degrees of freedom for error become extremely small. The sensitivity of the two-way AOV is demonstrated by the fact that in the one-way AOV, calculated to detect differences in the overall means for stations, only two variables (water temperature and pH) were significant. However, after accounting for the differences among side channel means by use of the two-way AOV, significant differences among station means for eight variables were detected (Table 2).

146. In summary, of the AOV's calculated to detect differences among side channel means shown in Table 2, seldom is the one-way AOV significant when the two-way AOV is not. The results of the two-way AOV for differences among side channel means after accounting for station differences are essentially the same as the results of the one-way AOV discussed earlier.

Relationship of benthic organ-
<u>isms to substrate type and depth</u>

147. In order to determine the nature and strength of the relationship among benthic organisms, substrate type, and depth, it was necessary to limit substrate types to three primary classifications and eight secondary classifications (Table 3). Percent composition by substrate type of substrate samples was based on the Unified Soil Classification System.[33]

148. <u>Substrate type.</u> To detect differences in the mean number of organisms for primary substrate classifications, a one-way AOV was calculated. The mean number of organisms observed associated with clay and

silt did not differ significantly ($P < 0.05$) from each other; however, both differed from the mean number of organisms associated with sand.

149. A second one-way AOV was calculated to determine if differences between secondary classification means existed within primary classifications. It was determined by this analysis that the secondary classification of substrates did account for additional variation in the number of benthic organisms.

150. It was found by employing the LSD that within the primary class sand, mean numbers of organisms associated with the three secondary classes (sandy, silty sand, and clayey sand) did not differ from one another. Within the primary class clay, significant differences between the mean number of organisms associated with the four secondary classes (clayey; silty clay; sandy clay; and sandy, silty clay) were observed. The main difference was that more organisms were found to be associated with the clayey substrate than with the remaining three secondary classes. No differences in the mean numbers of organisms for the three remaining secondary classes were detected.

151. The differences among the means for the secondary classes within the primary class silt were somewhat erratic due to the small number of observations. The significant differences detected were that the mean number of organisms associated with sandy silt differed from that of sandy, clayey silt; however, it did not differ from the mean associated with clayey silt or silt alone. The mean number of organisms associated with sandy, clayey silt differed from the mean associated with silt; however, the mean for sandy, clayey silt did not differ from the mean for clayey silt.

152. <u>Depth.</u> It was also of interest to determine if depth might account for any additional variation in the number of benthic organisms observed over and above what was accounted for by the different substrate classifications. By analysis of covariance, no significant relationship was detected between depth and the number of organisms after the substrate effect had been included in the model.

Student's t-Tests

153. To accommodate the different kinds of information gathered from side channels and river border areas during sampling periods II and III, two different types of analyses were made to test for differences among side channel and adjacent river border area means. The square root or log transformation of the observed data was made where applicable and the statistical analysis computed a second time. However, as was true in the case of the AOV's, the results were essentially the same for both analyses (transformed and untransformed); therefore, the following discussion of data and analyses are for only the untransformed variables.

Sampling period II

154. During sampling period II, fish alone were collected from one station at each of 19 river border areas adjacent to the side channels. Collections of fish from the 19 adjacent side channels were made at 3 stations in each side channel. Four separate paired t-tests were calculated to detect differences among overall means for side channels and adjacent river border areas during sampling period II. The first analysis compared the mean of the three stations within each side channel and the single observation for the adjacent river border area. The second, third, and fourth paired t-test analyses compared the observation from each side channel sta 1, 2, and 3 with the single observation from the adjacent river border areas. Overall or marginal mean differences and significance for all four analyses are presented in Table 4.

155. Overall side channel versus adjacent river border area. The comparison of the overall side channel (the side channel observation was the average for the three stations within a side channel) and adjacent river border area means revealed that greater numbers and/or values of total fish, total young-of-year fish, young-of-year fish categorized as forage and sport, number of fish taxa, species diversity $\bar{d}$, and evenness index e occurred in side channels than in river border areas during sampling period II. Other significant differences where side channel means were greater than river border area means were noted, i.e.,

young-of-year fish categorized as commercial and adult/juvenile fish classified as commercial and sport. However, the number of observations for these latter groups was small.

156. Station versus adjacent river border area. Since fish were collected at 3 stations within 19 side channels during sampling period II, it was of interest to determine if the relationships between the river border area and each of the three different stations within the corresponding side channel were the same. The results of the analyses for each variable using each individual station observation and the river border area observation for each side channel were comparable to the results of the paired t-test using the station averages as the observation for each side channel. That is, significant differences between side channel station and river border area means were, in every case, reflected in the results of the latter test. No additional differences were detected by using the individual side channel station observation and river border area observation for variables where significant differences were not detected by a t-test using the station averages for a side channel as the observation.

157. For the variables studied, no one particular side channel station differed from the river border area more often than any other side channel station. However, overall mean differences for side channel sta 2 were greater considering total fish, total young-of-year, and young-of-year fish categorized as forage and sport. Conversely, overall mean differences for species diversity $\bar{d}$ and evenness index e for side channel sta 2 were less when compared with those corresponding overall mean differences for side channel sta 1 and 3.

Sampling period III

158. During sampling period III, physicochemical measurements, benthic organisms, phytoplankton, zooplankton, and fish collections were taken from four side channels and adjacent river border areas with three stations at each location. Since the multiple observations at a particular river border area can be considered as replications, the paired t-test was not calculated for the observed values during sampling period III. An error term was calculated using the replications from the river

border areas within a location, and a simple t-test was then performed to detect differences between the overall means of side channel and river border area locations. The overall mean differences and significance are presented in Table 5.

159. Physicochemical variables. Significant differences for all surface and bottom physicochemical variables except water temperature were observed among the four side channel and adjacent river border area means during sampling period III. Mean surface dissolved oxygen concentrations and mean surface and bottom pH and alkalinity values were significantly greater for side channels. However, mean surface and bottom turbidity values were greater for river border areas. Mean bottom dissolved oxygen concentrations were significantly higher for river border areas than for side channels. Chemical stratification of the water column, which was developed in the more lenticlike side channels and absent in the river border areas, accounted for lower bottom concentrations of dissolved oxygen observed among side channels.

160. Benthic organisms. Among the variables grouped under benthic organisms, mean total numbers, mean numbers of oligochaetes, and mean numbers of pelecypods were significantly greater for side channels than for river border areas. It is interesting to note that, among the variables related to benthic organisms, while only a few significant differences were observed between the two habitats, side channel means were greater than river border area means.

161. Phytoplankton. No significant differences were discerned between side channel and river border area means for any variables associated with phytoplankton. Nonetheless, mean values for species diversity $\bar{d}$, evenness index e , and numbers of Chlorophyta and Chrysophyta were greater among river border areas. Mean values for numbers of Euglenophyta and Cyanophyta and total numbers per liter were greater among side channels.

162. Zooplankton. For those variables associated with zooplankton, only the mean value for species diversity $\bar{d}$ and the mean number of adult rotifers were found to be significantly greater among side channels. No other significant differences between the two habitats were observed for zooplankton.

163. Fish. Of the fish collected during sampling period III, no significant differences between side channel and river border area means were detected in the statistical analyses. However, except for total adult/juveniles and sport fish grouped in the young-of-year and adult/juvenile age classes, the means for all other variables were higher for the side channels than for the river border areas.

Comparison of sampling periods II and III

164. The reach of the Mississippi River in this study is characterized by a highly dynamic physical regime. The related sport and commercial fishery is considered to be relatively unproductive compared to the adjacent upstream pooled section, and is thought to be affected by abiotic parameters, primarily highly variable river discharge, and associated extreme water level fluctuations.

165. High-water stages normally occur within this reach of the river during spring and early summer. During sampling periods II and III, which took place during spring high water, maximum river stages recorded at St. Louis were 24.7 ft and 40.5 ft, respectively, with 30 ft, St. Louis Gage (SLG),* considered as flood stage. The initial sampling was conducted in June 1972 just after a high-water period on the river when water levels were receding. As a result, a few side channels or a few sampling stations within side channels were noticeably different, physically, from the remainder of the side channels or sampling stations. This observed physical difference was tentatively attributed to slack-water conditions within those few side channels or sampling stations. According to published literature,[34] a number of the more important commercial and sport fish species inhabiting this reach of the river typically spawn during the spring to early summer months, which parallel normal high-water conditions on the river. Physical schematics of individual side channel morphology (in Appendix C of Reference 30) indicated that, for sampling periods II and III, the majority of side channels

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* Elevations given in the remainder of this part are referenced to the SLG.

were characteristically riverine in nature for much of the assumed spawning period.

166. Effect of maximum controlling elevation. Although velocity measurements were taken within all side channels where flow was observed it was felt that these data would reflect only a point-in-time condition and would not reflect conditions prior to or after sampling (i.e., during the reproduction and early development periods). It was thought that the maximum elevation controlling or impeding flow through a side channel or sampling station would be a better criterion to measure the relative ability of a side channel to create slack-water conditions. The side channels were arbitrarily divided into three groups based on the maximum controlling elevation present within each side channel: $\leq$15 ft, 15 to 20 ft, and $\geq$20 ft. Data used in determining maximum controlling elevations were derived from the schematics of individual side channels.

167. Simple t-tests were performed to test for significant differences among the three side channel groups using the following criteria: mean total number of young-of-year fish; mean total number of young-of-year species; mean total number of young-of-year sport fish; mean total number of young-of-year sport fish species; mean total number of young-of-year forage fish; and mean total number of young-of-year forage fish species. The results of the test are summarized in Table 6.

168. The analyses indicated that, for the two sampling periods for which data were collected, no significant trends existed between the $\geq$20-ft grouping and the 15- to 20-ft grouping, nor between the 15- to 20-ft grouping and $\leq$15-ft grouping. While other significant differences were observed, the only significant trend for both years was for the parameter, mean total number of young-of-year sport fish; this parameter was significantly higher at the 5 percent level of significance both years for the $\geq$20-ft grouping as compared to the $\leq$15-ft grouping. These trends indicate that for the two consecutive years in which data were collected, the difference observed may be due to maximum controlling elevations lying somewhere toward the center of the 15- to 20-ft groupings. There were no significant differences between the $\geq$20-ft group and the 15- to 20-ft group, but there were differences noted

between the ≥20-ft group and the ≤15-ft group.

169. The data were rearranged into two maximum controlling-elevation groups for comparisons: <17.5 and ≥17.5 ft. Tests for significant differences were made between these two groups for the same parameters, and results are listed in Table 7.

170. The significant trends observed between the >20-ft group and the <15-ft group were similarly observed when reevaluated by comparing the ≥17.5-ft group with the <17.5-ft group. This indicated, tentatively, that any significant differences in fish population as a function of controlling elevation did not vary between the two sampling periods.

171. Habitat preference. The significance of the controlling elevation of the side channel was further evaluated by grouping the young-of-year species by habitat preference. Data on habitat preferences were obtained from the SIU literature review and include only those species that were discussed in that report.[34] The groupings, presented in Table 8, include those species adapted primarily to slack water or lentic habitats, those species adapted primarily to flowing water or lotic habitats, and ubiquitous species that are found frequently in both lotic and lentic habitats or that show preference for both during some stage of their life cycle. The three groups were tested for significant differences as a function of ≥17.5- or <17.5-ft controlling elevation. Results are listed in Table 9 and discussed below:

a. Lentic group. Significant differences were observed in numbers and species of lentic-adapted young-of-year fish for both sampling periods. During 1972 (sampling period I), numbers of sport young-of-year fish were significantly higher at the 1 percent level of significance, and mean total number of species was significantly higher (5 percent level of significance) in the ≥17.5-ft side channel group. During 1973 (sampling period II), mean total numbers of sport fish and mean total number of species of sport fish were significantly higher at the 1 percent level of significance in the ≥17.5 side channel group.

b. Lotic group. No significant differences were found between the two side channel groups for either mean total numbers of lotic young-of-year or for mean total number of lotic species for either sampling period.

c. Ubiquitous group. No significant differences in mean total numbers or in mean total number of species were observed between the side channel groups for either sampling period.

172. Slack-water hypothesis. In summary, the following hypothesis was tested: Those side channels or those sampling stations within side channels that provide slack-water conditions during normal spring high-water periods will provide a more suitable habitat for the survival and growth of young-of-year fish populations.

173. Mean total numbers of young-of-year were significantly greater for the ≥17.5-ft group during sampling period I, although no significant differences were observed for that parameter between groups for sampling period II. Conversely, the mean total number of species parameter and the mean total number of sport fish species parameter were significantly greater in the ≥17.5-ft group for sampling period II, while no significant differences were noted between the two groups for sampling period I. During the summer months, Ragland[29] observed a significantly greater catch per unit effort of young-of-year fish in these side channel areas, as compared to the river border areas, but this trend was reversed during the early fall season. This trend could be accounted for, in part, by the greater mobility of the young-of-year fish with increased age and their probable tendency to move in and out of the side channels with highly fluctuating water levels characteristic of this reach of the river.

174. The slack-water hypothesis appears to be valid when evaluated for the young-of-year by habitat preference for the two years for which data were obtained, but only for the lentic-adapted species. Significantly greater numbers of young-of-year lentic-adapted fish were found in those side channels of ≥17.5 ft for both years as compared to those side channels with a controlling elevation of <17.5 ft. Significantly greater numbers of lentic-adapted species were observed for the ≥17.5-ft side channel group during sampling period II. This can probably be best explained as a habitat preference of the lentic-adapted species for slack-water conditions.

175. The results of the comparison of fish data between side

channels and river border areas for both sampling periods should be viewed cautiously for the following reasons. Of major concern is the question relating to the relative effectiveness of seining in side channels versus river border areas. In the field it was difficult to evaluate this question. Although catch data from each habitat type were compared on the basis of equal sampling effort, it was felt that fish were more easily caught in side channels. In addition, since the number of fish collected and degrees of freedom for error were small, especially during sampling period III, statistically the probability of a type II error (accepting the null hypothesis when the alternative hypothesis is true) was rather large. While results from the simple t-tests indicated that there were no significant differences among side channel and river border area means, one cannot assume that, in fact, such differences might not exist.

Correlations

176. To help show the relationship between morphometric, physical, and chemical variables and biological variables, the data from all 23 side channels were subjected to correlation analysis. Thirty-two variables were selected for correlation analysis, and the results are presented in matrix form (Appendix B). The results of the analyses for certain variable groups that were thought to be important were selected from the table for presentation in the body of this report. The results of correlation among three physical variables, three chemical variables, and three morphometric variables with total number of benthic organisms, total number of fish, zooplankton density (numbers per liter), and phytoplankton density (numbers per liter) are shown in Table 10.

177. The physical- and chemical-related variables of water temperature, dissolved oxygen, and pH were negatively correlated with benthic organisms. Volume, a morphometric characteristic, was also negatively correlated with benthic organisms. Total number of fish was not significantly correlated with any of the physical, chemical, or morphometric variables selected.

178. Among the chemical variables, total alkalinity was correlated with zooplankton density, and pH was negatively correlated with phytoplankton densities. Surface area was highly correlated with zooplankton densities. Discharge was negatively correlated with both zooplankton and phytoplankton densities. A direct relationship was found between shoreline development and phytoplankton densities.

179. In summary, significant correlations of morphometric, physical, and chemical variables with biological variables were not restricted to or monopolized by any of these three variable groups. Comparison of the three variable groups indicates that more significant correlations occurred between chemical variables and biological variables than among morphometric and physical variables and biological variables, although the differences were small. Benthic organisms were most highly correlated with all variable groups; total fish did not correlate with any other variables presented.

Regression Analyses

180. Unlike correlation, a regression analysis produces an equation that describes the nature and strength of the relationship between variables. The estimated simple or multiple regression coefficient is a measure of how much increase or decrease in the dependent variable may be expected from a unit change in the independent variable. While regression serves a predictive function, it also is useful in understanding mechanisms or cause-and-effect relations. Since data from several side channels, each possessing unique characteristics, were used in the analysis, the utility of predicting standing crops of the biological variables for a particular side channel was not the main intent of the regression analysis.

181. The statistical computer program BMDOZR,[35] Stepwise Regression, was used to make the computations. The stepwise procedure used was as follows:

a. The first independent variable included in the equation was the one having the largest correlation with the dependent variable; i.e., the independent variable that

alone accounted for the most variation in the dependent variable.

b. After the first independent variable had been included in the equation, the remaining independent variables were analyzed to determine if any additional variable might account for a significant amount of variation in the dependent variable ($P < 0.05$) over and above the variation that had been accounted for by the independent variable already in the equation. If such a variable existed, it then was included in the equation.

c. The remaining independent variables were searched again to determine if a third variable might be included in the equation, and so on.

182. Table 11 shows the results of using multiple regression analysis to evaluate probable cause-and-effect relations among selected variables, which included the following:

a. Biological variables (total number of benthic organisms; total number of fish, forage fish, and sport fish; zooplankton density; and phytoplankton density).

b. Physical variables (water temperature, turbidity, and discharge).

c. Chemical variables (dissolved oxygen, pH, and alkalinity).

d. Morphometric variables (volume, surface area, and shoreline development).

183. The regression analyses were based on data from 23 side channels. Table 11 is presented in a manner to facilitate interpretation of those classes of independent variables that explain a significant percentage of the variation of a particular dependent variable.

184. Regressions were computed from various combinations of variables but only those that explain significant ($P < 0.05$) proportions of the variation of a particular dependent variable were included in the equations. The regression equations, shown in Table 12, are presented to allow inspection of the sign and magnitude of the partial regresssion coefficient, which indicate the direction and degree of change in the dependent variable unit change in the independent variable.

185. Combined biological variables from Table 11 explain 41 percent of the variation for benthic organisms; fish account for only 3 percent of the combined biological variations. When certain biological

information is available, various morphometric variables can be used to explain 53 percent of the variation for benthic organisms. The third entry shows that chemical characteristics, such as pH, will improve the ability to predict the mean number of benthic organisms. Physical variables such as temperature, turbidity, and discharge did not significantly explain any of the variation associated with numbers of benthic organisms.

186. Regressions computed for total fish showed that biological, chemical, and physical variables explained about the same proportions of the variation for total number of fish. For forage fish, morphometric, chemical, and physical variables explained approximately equal amounts of the variation. The total variation explained in both cases (total numbers of fish and forage fish) was low, 24 and 19 percent, respectively. On the other hand, 64 percent of the variation associated with mean numbers of sport fish was accounted for by three classes of variables. Among the biological and morphometric variables, benthic organisms, phytoplankton density, and surface area explained significant proportions of the variation associated with sport fish. Volume and turbidity contributed an additional 9 percent to the variation explained.

187. Dissolved oxygen explained 15 percent of the variability associated with zooplankton density; however, it accounted for 38 percent of the variability associated with phytoplankton density. Benthic organisms were significantly correlated with zooplankton and phytoplankton densities and explained 5 percent and 24 percent, respectively, of the variation. Shoreline development explained 4 percent of the variability associated with zooplankton density. Zooplankton density was significantly correlated with phytoplankton density; however, zooplankton density accounted for only 4 percent of the variation in phytoplankton density.

188. The results presented here do not provide input for a clear interpretation of cause-and-effect interrelations among biological, physical, chemical, and morphometric variables. No trends were observed in the multiplicity of effects to account for the variability associated with the various dependent biological variables. That is to say, no one class of variables, e.g., morphometric, consistently explained a greater

portion of the variability associated with each specific biological variable tested. Considering all the dependent variables tested, the relative percent of the variation explained by the four variable classes, in decreasing order, is as follows: biological, chemical, morphometric, and physical.

PART VI: SIDE CHANNEL RANKINGS

189. If it is agreed upon that side channels are important to the ecology of the river and that not all of them would be maintained or improved, a decision must be made as to which side channels are most important.

190. Although it is generally recognized that most side channels are transient features of the river, it may be possible that some could be maintained or improved to provide maximum benefit to the river's ecology. To make a rational choice from among all side channels of those channels that could provide the most benefit requires baseline information related to the abundance and composition of aquatic communities that the side channels support. The baseline data established in the present study were the first of their kind for this area and hopefully will allow comparisons of these areas with future investigations.

Relative Importance of Each Side Channel

191. With this information in mind, it was desirable to determine the relative importance of each side channel by ranking them on the basis of biological groups: namely, fish, benthic organisms, zooplankton, and phytoplankton. Average total numbers and species diversity $\overline{d}$ for each of the biological groups were used in the ranking procedures. The basic assumption was that within a side channel, the larger the standing crops of organisms and the more diverse the communities, the more valuable the side channel. Large standing crops of certain organisms can occur even in polluted systems, but usually the diversity of such a community is low. For this reason, both standing crops and diversity were used as criteria in ranking.

192. The selection of subgroups within each of the biological groups used in the ranking procedure was based mainly on those subgroups that were numerically dominant. Many of the subgroups for which there were data (predator and commercial fish and benthic organisms, such as crustaceans, leeches, and gastropods) were so poorly

represented that their contribution to the ranking procedure was considered unimportant and therefore they were not included. Phytoplankton and zooplankton total densities and diversity were considered to be the most meaningful and were the only planktonic subgroups considered.

193. Since not all biological groups were sampled consistently for all side channels and during all three sampling periods, an attempt was made to employ the maximum amount of information available that was considered meaningful in the ranking procedures. This meant making two final rankings of the side channel where:

a. All 23 side channels were ranked.

b. Only 13 of the 23 side channels were ranked.

The biological subgroups used to derive the final rankings for each sampling period are presented in Table 13.

194. In the determination of side channel ranks, mean values for each subgroup within each sampling period were used to calculate grand means over the three sampling periods. Subgroup grand means for each side channel were assigned ranks with the largest mean given a rank of "1," the next largest mean a rank of "2," and so forth. Individual subgroup ranks were combined to derive group rankings for the groups of 23 and 13 side channels. Group ranks for each side channel were added to obtain two final overall side channel rankings. Group rankings and the corresponding overall side channel rankings are presented in Tables 14 and 15.

195. When group ranks were compared with the final rank for a particular side channel, there appeared to be no consistent trend that showed any group to be a better indicator than any other of the overall value of the side channels. Had a consistent trend been observed, future monitoring of the side channels would require only evaluation of that particular group. Such a reduction in scope of investigating these aquatic habitats would have resulted in less effort and cost.

196. The ranks for the 13 side channels are based on more information than the ranks for all 23 side channels and for this reason should provide a better ranking for those specific locations. However, comparison of the ranks of the 13 side channels (Table 15) with the

ranks of the same 13 side channels ranked among the 23 (Table 14) reveals that while some differences exist, generally the order of ranking is comparable in both cases. The similarity in ranking order observed between the final two rankings for those specific 13 side channels is due to the fact that most of the information used in the ranking procedures is common to both final rankings. While the ranking of the 13 side channels provides a better evaluation for those side channels, it is limited in that only 13 side channels were evaluated.

197. The evaluation based on the ranking for 23 side channels appears to be more valuable from the standpoint that a greater number of side channels were considered. Additionally, the results from the ranking of the 13 side channels may help to differentiate between two or more closely ranked side channels observed in the ranking of the 23 side channels. For example, side channels 10 and 23 both have an overall rank of 10 based on the rankings of all 23 side channels (Table 14). However, by basing the rankings on more information (Table 15), side channels 10 and 23 are differentiated and assume new ranks of 1 and 4, respectively.

Factors Affecting the Longevity of Side Channels

198. Primary interests in the 23 side channels considered in the present study are related to the abundance and composition of aquatic communities occurring in them. Also worth considering in addition to biological characteristics are those factors that affect the longevity of side channels. Undoubtedly, certain side channels could be maintained to provide maximum benefit to the river's ecology more easily than others. While individual model studies for each side channel could provide the best criteria for such decisions, there are some general comments that can be made that provide some insights relevant to why certain side channels persist in time while others do not.

199. The cross-sectional geometry of the river affects the entrance and exit conditions of a side channel. If either the entrance or exit of a side channel is located in an area of deposition, the side channel is less likely to remain open. A typical depositional area is

at the inside of a bend. The helical flow pattern in river bends (Figure 24) results in a scour tendency on the outside and deposition on the inside of a bend.

200. Another example of the effect of helical flow concerns the discharge of sediments at a bifurcation. The bed load (coarser sediments carried along the bed of the river) is carried predominantly to the inside of the bend (Figure 25). This could lead to the blockage of the side channel entrance if the side channel is located on the inside of a bend. Referring to Figure 24, the increased water elevation of the

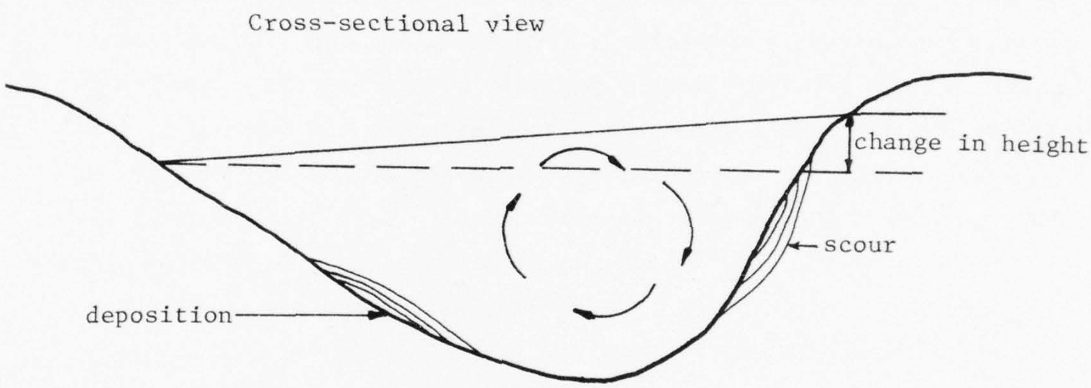

Figure 24. Flow pattern at a river bend

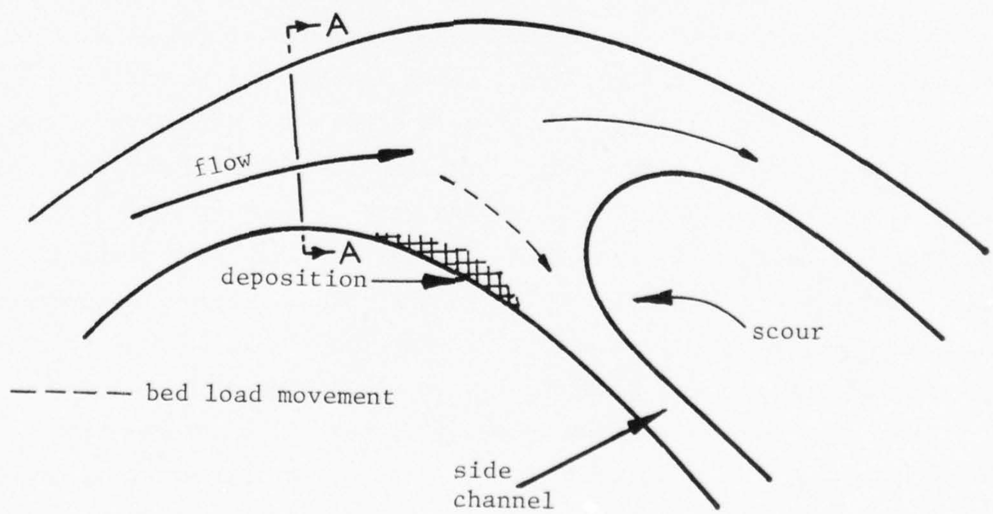

Figure 25. Tendency of bed load to move to the inside channel

flow on the outside of the bend carries less of a suspended load (solid matter carried by a river in suspension) and, consequently, a side channel located on the outside of a bend in the river receives less of a sediment load.

201. In general, the concentration of suspended matter increases with depth (Figure 26). The lower the suspended load of the water entering a side channel, the smaller the chance of deposition and ultimate silting up of this channel.

202. The slope or head difference (the difference in water-surface elevation at the entrance and exit of the side channel) is important. If the head difference is greater than that of the river (in other words, if its path is shorter than that of the corresponding reach of the river), the side channel will attract flow, especially during higher stages. Scouring will generally be greater and the side channel will subsequently be longer lived.

203. Roughness is another important factor regulating the flow

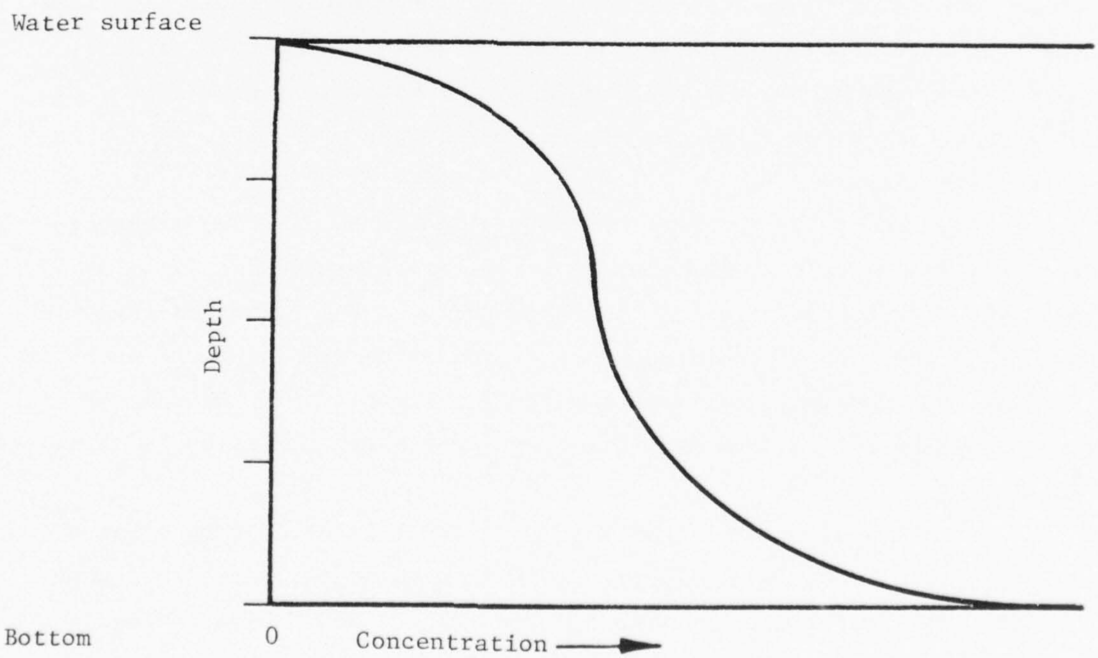

Figure 26. Suspended load concentration versus depth (after Prins[36])

in side channels. Vegetation, irregular sections, and dikes contribute to the roughness which results in a depositional environment which decreases the longevity of a side channel.

204. The location of a side channel can be on (a) a straight reach, (b) the inside of a bend, or (c) the outside of a bend.

205. Long, straight reaches are believed to be the result of a combination of natural or man-made cutoffs where long reaches of sinuous, meandering channels with relatively flat slopes are converted to shorter reaches with steeper slopes which gradually diminish with development and degradation of the channel upstream. These slopes are flattened at high stages but are still steep enough to enable the stream to transport large quantities of bedload sediment. This results in wide channels with shallow average depths and bed forms that are maintained by these steep slopes. At low stages the river tends to meander within the high-water trace, resulting in short pools between relatively long and shallow crossings not suitable for navigation. The pools cause converging flows that tend to deepen, followed by diverging flows that contribute to the higher crossovers and the formation of middle bars. Even though the plan view during high water appears relatively straight, the channel tends to meander within the confines of the high-water line (Figure 27).

206. Referring to Figure 27, any side channel located along a straight reach would be handicapped if either the entrance, exit, or both the entrance and the exit were located at a bar formation (Figure 28). Because of the straight reach, the side channel would probably have a lesser bottom slope than the river. Any dikes in the channel would further retard flow and thus the side channel's ability to maintain itself.

207. A side channel that begins on the outside of a bend has a favorable entrance position since it is in a nondepositional area and the flow carries a lesser suspended load (Figure 29). Side channels that occur on the inside of a bend would probably have entrances and/or exits located in a depositional region (a bar formation). The entrance would receive a disproportionately high volume of bed load

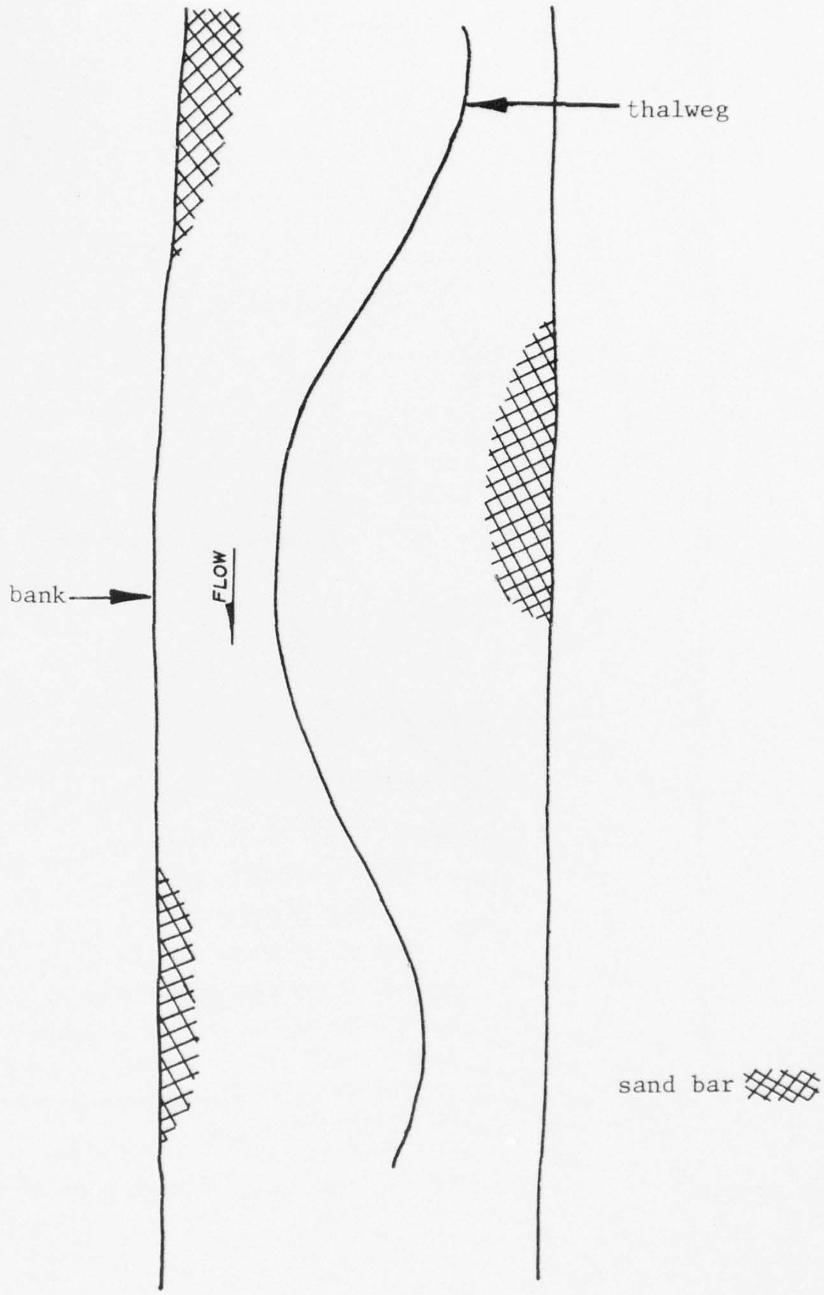

Figure 27. Meandering thalweg in a straight reach

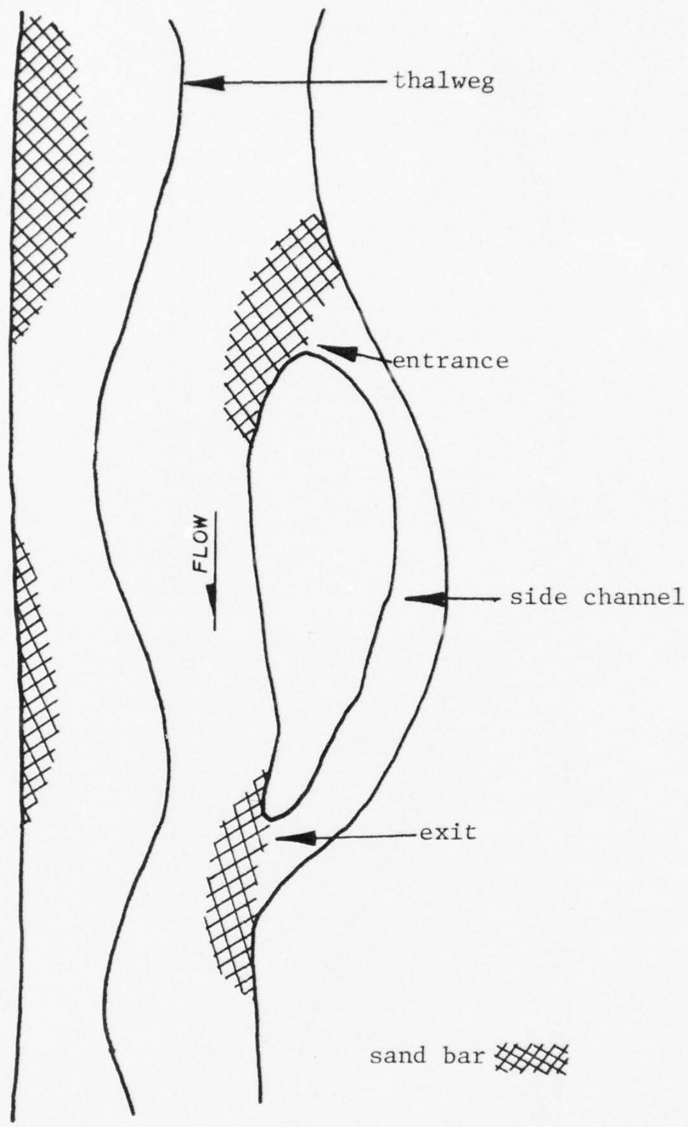

Figure 28. Side channel in a straight reach

that, when deposited in the side channel at lower stages, would greatly increase the channel resistance.

208. A closure dike in a side channel is meant to retard flow at low discharges and to pass flow at high discharges. It thus acts as a broad-crested weir. Because the dike diverts flow at low discharges to the main channel, the river is better able to maintain its navigation

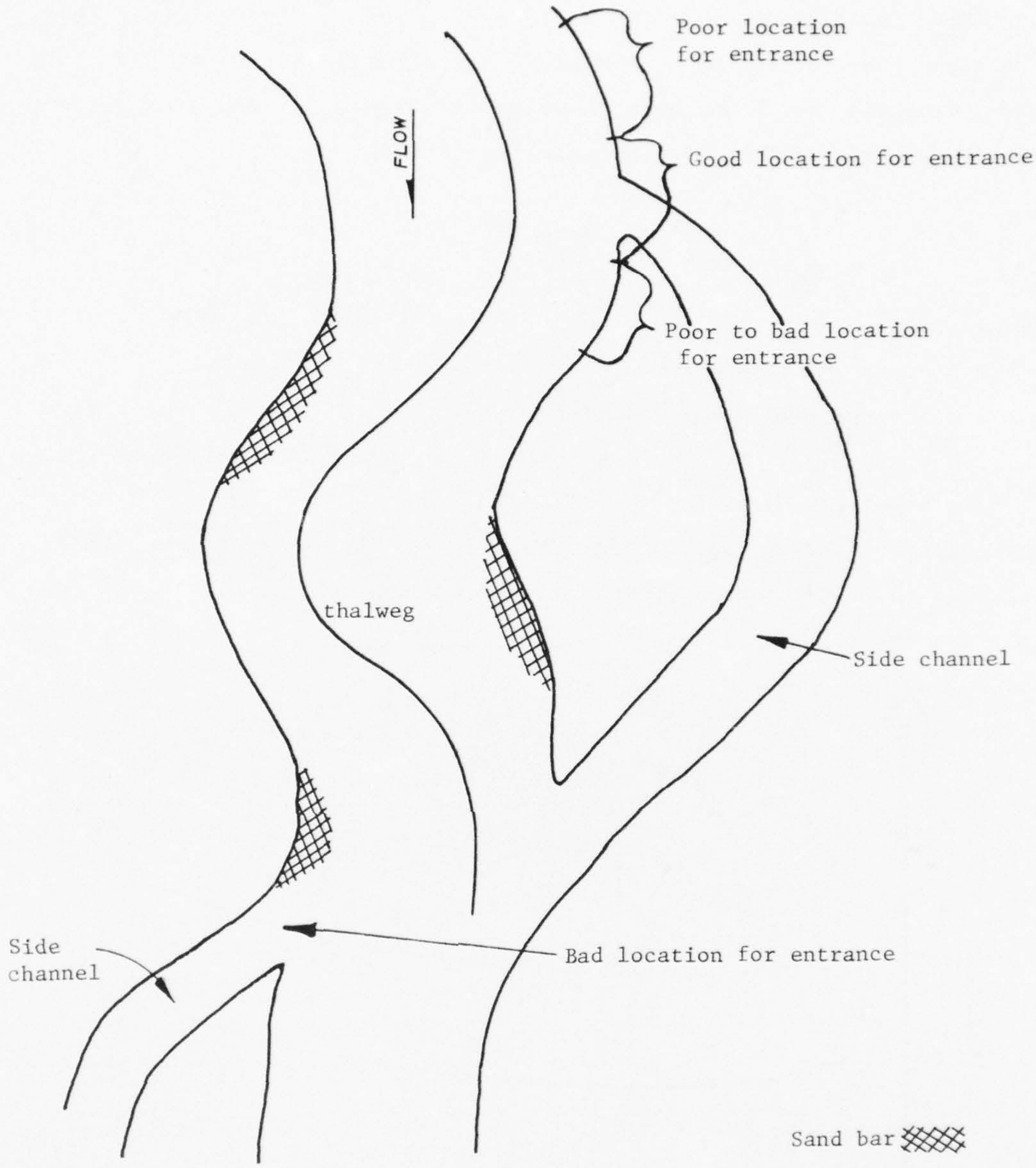

Figure 29. Idealized entrance conditions for side channels in bends

channel. If the closure dike can pass flows at higher discharges without creating too great a backwater effect, the dike functions well.

209. To notch a closure dike or even a dike in the river proper is to allow a small discharge to pass through the dike at a lower river stage. Two points to consider are (a) the equilibrium entrance

conditions to the notch and (b) the side channel into which the flow discharges. The flow passing the notch will generally enter into a large secondary channel unless this channel has already silted up. As sediment transport can be related to velocity (Figure 30) and average velocity can be represented by the following equation:

$$V = \frac{1.49}{n} R^{2/3} s^{1/2} \qquad (1)$$

where

V = average velocity

n = roughness factor (Manning's n)

R = hydraulic radius (area of channel divided by wetted perimeter)

s = bottom slope

any number of factors can affect the velocity necessary to keep solid material in suspension. Therefore, the downstream channel is the controlling factor.

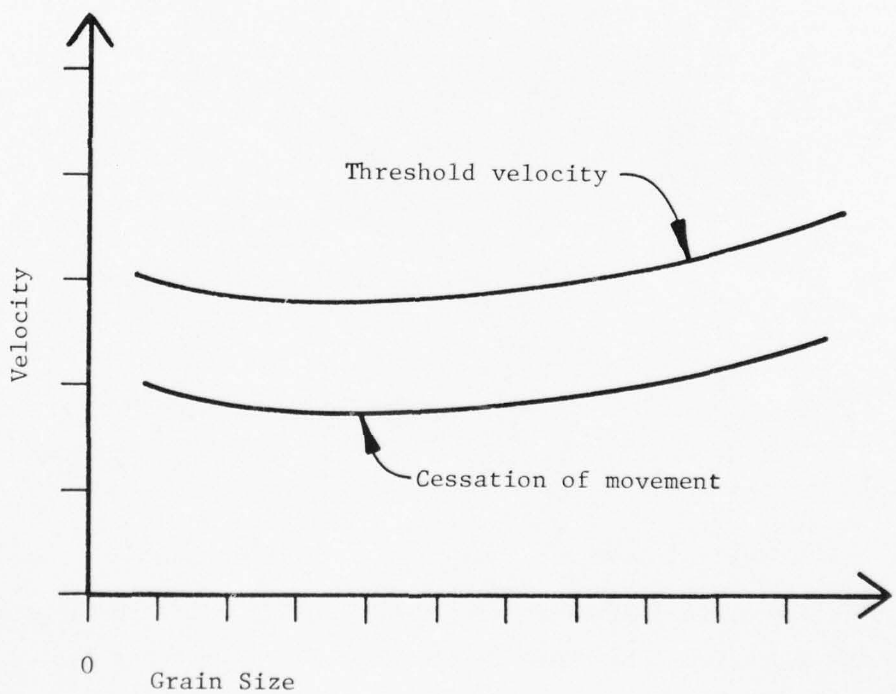

Figure 30. Sediment transport as a function of grain size and flow velocity (after Prins[36])

210. The removal of internal dikes within a dike field in a side channel obviously reduces the retardance to flow but affects the stability of the lead dike. In most cases, a single dike could suffice if it were properly designed.

211. The complexity of the problem concerning longevity of side channels does not lend itself to simple solution. Only a thorough hydraulic model study based on complete prototype data can give a satisfactory answer to a given situation.

PART VII: ENVIRONMENTAL IMPACT OF CONSTRUCTION, OPERATION, AND MAINTENANCE

212. The environmental impacts of the present methods of construction, operation, and maintenance of the Middle Mississippi 9-ft-deep, 300-ft-wide channel will be considered in this section. Operation and maintenance activities include maintenance dredging of the channel, disposal of dredged material, and the construction and maintenance of dikes and bank revetments. The purpose of these activities is to provide adequate depths for commercial navigation, especially during periods of low flow.

213. As stated earlier, the river was essentially unaffected by developments prior to the twentieth century. Most of the changes, in response to man-induced developments or modifications, have occurred within the twentieth century. In general, these changes are related to river morphology and river behavior which either directly or indirectly affect the biotic communities through the modification of existing habitats. It is important to maintain the perspective that historically, significant changes of the river system have occurred naturally since the end of the period of glacial melt and will continue to occur with or without man-induced modifications.

214. In discussing environmental impacts, it is also important to realize that different reaches of the river and the structures within these reaches respond differently to modifications. Especially in the case of side channels, no general formula can be used to predict changes or even to assess existing conditions without a detailed study of each specific reach; even then predictions are difficult.

Maintenance Dredging

215. Dredging in the Middle Mississippi is required to maintain or improve the navigation in the main channel. Generally, much of the concern associated with dredging and disposal operations involves closure of side channels or backwater areas and the direct destruction

of benthic communities that are an important part of the riverine ecosystem. Direct destruction of commercially valuable species such as mussels and clams is another concern. The direct effects of dredging and disposal on benthic communities appear obvious; yet definitive information allowing the prediction and assessment of the extent, duration, and significance of these effects has not been documented. In general, however, the potential for the direct destruction of benthic communities is greater in areas which have not previously been dredged than in areas where dredging has occurred. Previously dredged areas characteristically have shifting substrates that may limit successful benthic colonization.

216. Twelve previously dredged sites, 15 disposal sites, and 3 river border areas in the Middle Mississippi River were sampled for benthic organisms in September 1973.[37] Lowest abundance and diversity of benthic organisms were observed for all dredge sites, greater abundance and diversity were observed at disposal sites, and highest abundance and diversity were observed at river border areas. Among all previously dredged sites, total numbers of organisms ranged from 0 to 4 organisms per 0.16 m^2; the number of taxa ranged from 0 to 2 per 0.16 m^2. Samples collected from 4 of the 12 dredged sites contained no organisms. Since samples were not collected in the main river channel from other than dredging sites, no valid comparison between previously dredged sites and those sites in the channel with no dredging history was possible. However, data from three river border areas in the same river reach with no dredging or disposal history may serve to give a relative indication of the difference in abundances between the two areas. The results from 23 samples revealed greater numbers of both organisms and taxa. Among these river border areas, total number of organisms ranged from 3 to 186 per 0.16 m^2 and averaged 34 per 0.16 m^2. Number of taxa ranged from 1 to 9 and averaged 5. It was apparent, at least on a relative basis, that numbers and kinds of benthic organisms occurring in previously dredged sites were low when compared to river border areas that had no dredging history. However, it is felt that even those areas in the main channel not requiring maintenance dredging provide

poor habitat for benthic organisms. While further research is needed, present data indicate that the main channel of the river is characterized by strong current and shifting sand bed load, which would severely limit benthic populations.

217. Indirect effects of dredging on aquatic communities are also an important concern, although much more difficult to evaluate. The potential for indirect effects is most often attributed to physical alterations of the environment and possible release of toxic materials and nutrients in the water column.

218. Among the physical alterations as a result of dredging are changes in bottom geometry and bottom substrate that cause subsequent alterations in current patterns, velocities, and possible nutrient or toxic chemicals exchange between sediments and the overlying water. These physical alterations may work individually or synergistically to initiate different responses within aquatic communities.

Disposal of Dredged Material

219. Most of the concern associated with the disposal of dredged material in the Middle Mississippi River involves the effects of open-water disposal on water quality and aquatic organisms and the closure of side channels. Prior to the assessment of the effects, knowledge is needed regarding the quantity and quality of the material to be dredged. This is an enormous task considering that the types of materials, quantities, rates, and methods of disposal vary greatly with time and location.

220. It is well established that within the study reach, bottom sediments are continually being resuspended naturally, and to a degree, open-water disposal of dredged material can be thought of as an extension of these natural processes. However, open-water disposal usually results in the resuspension of large volumes of sediments within a shorter time and in a limited area. The resuspended sediments may contain toxic chemicals and nutrients that, through the process of dissolution, may enter into solution and adversely affect biological communities.

221. Short- and long-term effects of open-water disposal on water quality and aquatic communities are yet to be thoroughly evaluated, but nonetheless some are qualitatively known. Short-term effects associated with disposal operations include:

a. Increased turbidity that reduces light penetration and could therefore interfere with primary production, flocculate plankton organisms, decrease food availability, and produce effects which are aesthetically displeasing.

b. Increased sedimentation that could result in the smothering of benthic organisms, destruction of spawning areas for fish, and the reduction of habitat diversity and vegetation cover.

c. Reduction of dissolved oxygen concentration that could suffocate or stress organisms in the immediate vicinity and/or release noxious materials such as sulfides, methane, and heavy metals into the water column.

222. Unlike short-term effects, which usually can be detected during or immediately after the disposal operation, possible long-term effects are more subtle and thus more difficult to detect and evaluate. The possibility of long-term effects as a result of disposal operations is attributed to the presence of nutrients and chemical toxins in the sediment, their release, and their possible subsequent effect on the extent, rate, and diversity of the recolonization of benthic populaations. Undoubtedly, through the selection of disposal sites that are poor aquatic habitats, the Corps can minimize any possible adverse effects of placement of dredged material on the aquatic ecosystem of the Middle Mississippi River.

223. The disposal of dredged material in such critical areas as near the entrances or exits of side channels may have deleterious effects. The direct placement of dredged material in these locations could block the flow of water through the side channels and thereby prevent the movement of fish between side channel and river and could reduce the flow and consequently alter existing physicochemical characteristics. It is now the practice of the Corps in the Middle Mississippi River to restrict the disposal of dredged material at the entrances and exits of side channels.

224. Knowledge concerning the most ecologically sound manner of disposal of dredged material is presently unavailable. WES has initiated, as part of the Dredged Material Research Program, studies that hopefully will provide definitive information relevant to disposal problems.

Levees

225. The construction of levees along the floodplain was one of man's first modifications to affect the natural flows in the Middle Mississippi River. The levees have isolated the major portion of the floodplain from the river channel so that all floodwaters are now confined to the river channel and that portion of the floodplain between the channel and the levees. Consequently, the flood stage has increased for similar discharges.

226. Since the floodplain is a storage area for floodwaters when the river rises above the bank-full stage and provides additional channel capacity to carry water downstream, levees along a reach of the river increase the flow discharge for stages greater than bank-full. The increase in channel discharge results from the decrease in floodplain storage.

227. Although flood stages in the Middle Mississippi are now higher than those under natural conditions, levees prevent flood damage outside of the levees when the river exceeds bank-full stage and by doing so prevent widespread destruction of terrestrial fauna and flora. Additionally, levees provide sanctuary during high water to many animals inhabiting the unprotected floodplain. Under natural conditions, widespread flood damages occurred whenever the river exceeded bank-full stage.

Dikes

228. To provide year-around river navigation in the Middle Mississippi River, over 800 dikes having a total length of 91 miles have been built into the river channel from the riverbanks. To obtain the 9-ft navigation channel in the study area, the Corps of Engineers is

presently extending the dikes so that the maximum distance between the ends of the dikes on opposite sides of the river is 1500 ft. The effects of dikes on river morphology and river behavior and subsequent effects on riverine ecosystems are numerous.

Areal reductions

229. Between 1888 and 1968, the river surface area in the study area was reduced by about one-third, the island area by one-half, and the riverbed area by one-fourth as a result of river contractions by dike fields and bank revetment. During this same period, average river width decreased from 5300 ft in 1888 to 3200 ft in 1968 due to contraction efforts. Dike construction began earlier in another reach on the Mississippi near St. Louis. Since 1849, dikes have reduced the river width of this reach by half. However, the bank-full width at St. Louis has remained at 2100 ft.

230. The cross-sectional area at bank-full stage measured at St. Louis in 1937 was 120,000 sq ft, which was reduced to about 80,000 sq ft in 1973. The narrowing of the channel at St. Louis has reduced the bank-full channel area by about one-third. Bank-full cross-sectional areas have similarly decreased throughout the Middle Mississippi River wherever the river channel has been contracted.

231. The cumulative effect of the reduction of areas, especially those shallow areas between the main river channel and the bank, has reduced the available habitat for those plants and animals adapted to such areas; however, this effect is yet to be quantified. The loss of the above specific surface areas must be viewed together with the newly created 91 miles of dike and the potential habitat they provide for aquatic organisms. Although further investigations are needed, WES field surveys of many dikes, both in side channels and along river border areas, during July 1973 indicated that the dikes examined provided excellent habitat for benthic organisms. Large numbers of nonburrowing mayflies and caddisflies plus other aquatic invertebrates were observed on the quarrystones of which the dikes were constructed.

Riverbed degradation

232. Riverbed degradation has also occurred along the Middle

Mississippi River wherever the river channel has been narrowed. The degradation is the natural consequence of reducing the width, increasing the flow per unit of width, and increasing the transport capability of the water per unit width. The effects of riverbed degradation on aquatic organisms in the reach of the Middle Mississippi River are not yet fully understood; it is possible that increased sediment load could adversely affect these organisms directly by smothering established populations and indirectly through alteration of their habitat.

Water-level fluctuations

233. Based on St. Louis river stage records beginning in 1843, the annual maximum stage at St. Louis has been increasing only slightly throughout the 130 years of records. The variations in annual maximum stages are greater now than in the past. The highest recorded stage in St. Louis was 43.3 ft in 1973. The trend of the annual minimum stages has been downward during the period of record. The minimum stages are now on the average 6 ft lower than in the 1860's and the 1870's. The lowest recorded stage at St. Louis was -6.2 ft on 16 January 1940. The study of the daily stage versus duration reveals that, on the average, daily stages are lower now than a century ago.

234. The changes in stage at St. Louis in the last century are due mainly to the rock and/or pile dikes and the levees. Construction of rock and pile dikes causes deposition in the dike field; trees and other vegetation grow on the deposit and stabilize it. The tree and willow growth encourages additional deposition whenever the area is flooded. In most cases the ultimate effect of the dike field is to cause the river to develop a new bankline at the extremity of the dike field, resulting in reduced channel width and a lowering of the riverbed. Because the bed is lower in the contracted river, the stages are lower.

235. In summary, increased variations in annual maximum stages and decreases in annual minimum and daily stages have occurred since man-made modification of the river began and have resulted in greater fluctuation of water levels than in the past. Fluctuating water levels have occurred throughout the Middle Mississippi River history. Side channels along the river have been and will continue to be subject to

the river's fluctuations; and since many of them are shallow, changes may be extreme within the side channels. Organisms living in areas with a history of water-level fluctuations have adapted to these conditions. It is felt that the impact of increased water-level fluctuations on organisms inhabiting side channels or areas within the floodplain is minimal due to their prior adaptation. More serious is the sudden lowering of water levels with subsequent reduction in volume and area that could adversely affect biological communities.

Side Channels

Stabilized channel

236. In the Middle Mississippi, there are some natural side channels that were formed by the processes of either erosion or deposition. Side channels so formed can grow in size and capture most of the discharge and become the main channel; they can deteriorate in size and become a part of the floodplain; or they can grow to the same size as the main channel and maintain that size. In the natural river, those side channels that are obliterated by deposition are replaced by new side channels caused by floods and/or river migrations.

237. The Middle Mississippi River is no longer free to migrate and produce new side channels since there are no meander loops to be cut off by floods. Except for those side channels that carry appreciable riverflows at high stages (chutes), natural side channels are being filled with sediment. The major chute channels such as Cape Bend have achieved a size that indicates that they could exist for a long period of time.

238. Today most of the more recent side channels in the Middle Mississippi are man-induced. These side channels form in and along the dike systems employed to improve the river navigation channel. The life of a side channel produced by dike fields is usually relatively short. The dike fields and the side channels fill with sediment rapidly because dike fields are usually located in areas of natural deposition. Once the side channel is filled, there is easy access to the

island area. In many cases, the filled side channel and island area are converted to agricultural use.

239. The major impact, however, is the loss of the side channel to the riverine ecosystem. Man-made or existing natural side channels are important features to the ecology of the river. They provide suitable areas for fish and wildlife habitats, as evidenced by studies performed by WES[30] and MDC.[29] How important they are to the river fishery is still a question in need of further study; yet the loss of side channels through whatever mechanism and corresponding loss of the potential to the river fishery is real. The loss of aesthetic and existing or potential recreational areas must be considered as part of the impacts associated with the loss of side channels. Their value as commercial fishing areas is very limited, but they are enjoyed by sport fishermen as well as boating enthusiasts. Since side channels serve as storage reservoirs during flood stages, slight increases in flood heights would occur if they were to disappear.

240. It is important to remember that not all side channels are equally important for aquatic organisms and other animal forms. Some provide more suitable habitat for fish and wildlife than others. Because of their alignment with the main channel, still other side channels may be short-lived and/or difficult to maintain. Such factors need to be considered if preservation of the side channels is planned.

River morphology

241. The life history of side channels and dike fields is evident in all reaches of the Middle Mississippi River. Dikes were built in the Middle Mississippi after the nineteenth century. In almost every reach, there are old dike fields that are completely covered by sediment and vegetation and are now indistinguishable from the mainland; there are both new and old dikes visible only where they cross backwater channels and at the main channel extremity; and there are new dike fields as yet not covered by sediments and vegetation. A side channel in a dike field passes through stages of development usually to a stage where the side channel is indistinguishable from the adjacent floodplain.

242. Model studies. CSU model studies have shown that single

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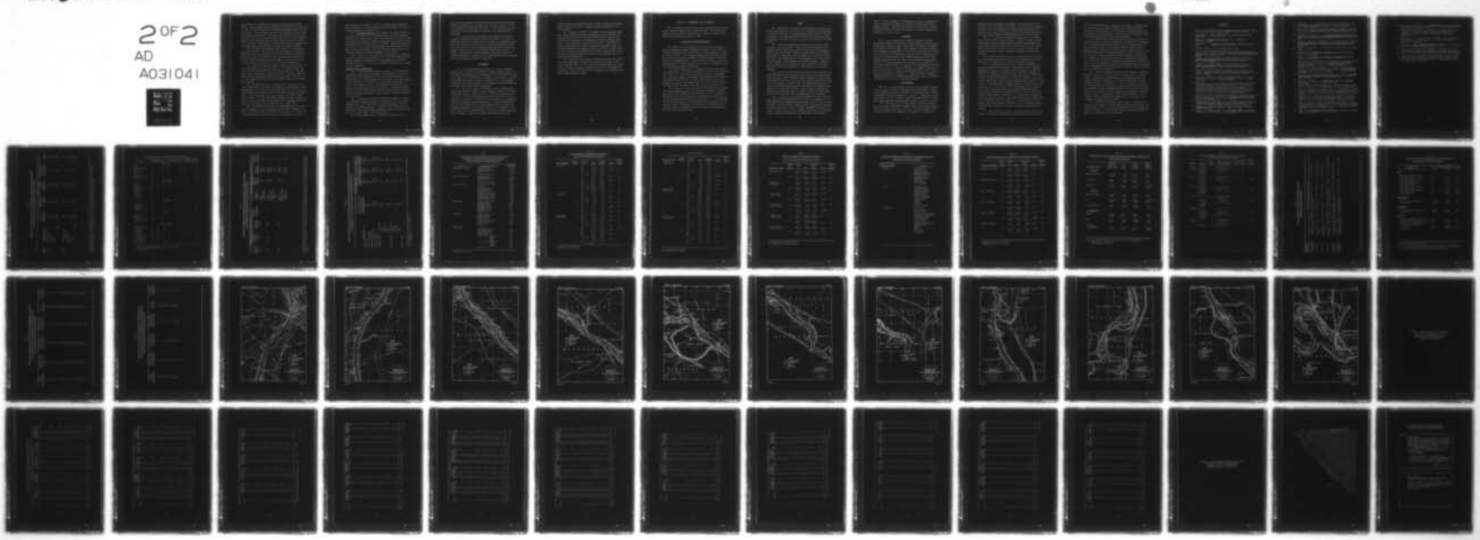

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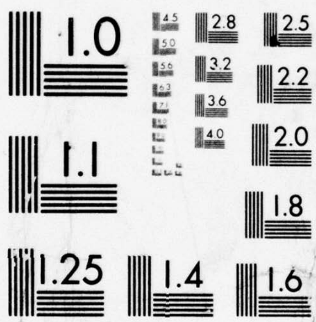

MICROCOPY RESOLUTION TEST CHART
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dikes affect river morphology and behavior differently than do dike fields. When a single dike is projected from one bank out into the channel flow, the flow velocities are increased, especially around the nose of the dike. These increased velocities scour material from the region around the nose of the dike. Because the bed velocities at the nose of the dike are still less than the surface velocities, it is the sediment-laden bed velocities that make the turn into the lee side of the dike. On the lee side of dikes placed in natural depositional areas, where the flow expands again, the sediments are deposited forming a sandbar.

243. The scour hole produced is much smaller in volume than the bar behind the dike. After the scour hole has reached an equilibrium depth, the flow field around the nose of the dike takes the normal bed materials moving in from above the dike and places these sediments on the bar. Thus in the model discussed earlier in this report, the bar continued to grow, even after the scour hole had ceased growing.

244. As soon as the bar is formed, a derelict channel is left in the area between the bar and the bankline. This channel accepts the flow over the bar and drains that flow out the lower end. If the bar were to become vegetated or otherwise stabilized, the small channel between the bar and the bank would become a side channel. The future of the side channel would depend on river alignment, discharge, and sediment transport.

245. Adding another dike in the model on the same side of the channel downstream of the single dike changed the bar-building processes significantly. The initial effect was that much less flow entered the region between the two dikes and more flow passed through the contracted section. The second dike blocked the discharge of the small channel along the bank. Less water and sediment entered the region between the dikes. The result was that the bar between the dikes grew and moved inward much more slowly than when there was only a single dike.

246. Laboratory model studies have demonstrated how scour holes, velocity changes, and the establishment and movement of sandbars are some of the physical impacts resulting from the presence of dikes. One very important impact associated with existing dikes and one that has

been observed in the field is the fact that dikes create slack-water areas and by doing so provide habitat diversity beneficial to fishes as resting, spawning, and foraging sites.

247. Prototype conditions. One important difference between the evolution that occurred in the laboratory model dike field described above and the evolution that occurs in the prototype dike fields is that in the prototype, vegetation becomes established on the surface of bars and alters the evolution processes. In general, vegetation impedes the flow across the top of bars and effectively stops the movement of sediment into the small channel. With the addition of trees, a bar would become an island with the small channel as a side channel.

248. In the case of the single dike, the addition of vegetation to the bar would help to preserve the life of the side channel by stopping the movements of large amounts of bed sediments over the bar. Sedimentation would still occur in the backwater channel but at a significantly reduced rate.

Changes in dike configuration

249. In the Middle Mississippi River, much of the planned dike construction includes short extensions of existing dikes. Field experience and model experiments by CSU show that short extensions of existing dikes into the main channel will not result in new side channels. A short extension of a dike field in natural depositional areas results in the formation of long, low bars between the dikes and a very shallow channel between the bars and the bank. If the dike extension crests are low, the entire area of the dike fields remains sand-filled. Vegetation becomes established on these sandbars if the dike extension crests are high.

250. If the area of the dike field becomes vegetated, a portion of the high-water-carrying capacity of the river is lost. The newly vegetated area is not as effective in carrying high-water flows as it was prior to becoming vegetated. In general, short extensions of existing dikes will produce a deeper low-water channel, no new side channels, and possibly higher stages during floods.

251. Model studies used to evaluate the effects of notched

dikes on river morphology have generally shown that the notch resulted in rapid sedimentation in the entire dike field and formation of scour holes immediately downstream of each dike. It was concluded that such scour holes would produce bankline failures if the banklines were not stabilized.

252. About 20 dikes in the Middle Mississippi River have been notched to determine the effects of the notched dike on the river's morphology and how such effects differ from those of the unnotched dikes. While the alterations are too recent for detailed evaluations, casual field observations of these prototype notched dikes tend to verify the results of model studies in that bankline failures were observed. In addition, deposition was observed upstream from notched dikes, and notched dikes appear to deteriorate at a much higher rate than unnotched dikes, especially during periods of high flow.

Revetments

253. In the Middle Mississippi River, 122 miles of revetments stabilize the riverbanks by preventing or greatly reducing erosion. By this method, bend migration has been reduced to the extent that the river is no longer free to migrate and to produce new side channels. The loss of potential new natural channels is offset by the fact that man-made channels have been formed through river development and modification and that these side channels could be maintained.

254. Some of the effects of revetments on river morphology and behavior are similar to those of dikes, since both revetments and dikes cumulatively serve to contract the river. CSU studies have shown that contraction of the river has generally caused the reduction of river surface area, island area, riverbed area, river width, and corresponding bank-full channel and cross-sectional areas. Because revetments have kept the river channel narrow, riverbed degradation has occurred with subsequent lowering of the riverbed elevation. As a consequence of the areal reductions, the potential habitat available for aquatic organisms has been reduced. However, preliminary field observations by WES

indicate that rock revetment may create a superior habitat by providing greater diversity for aquatic organisms through stabilization of the river's banks.

255. Although the effects of increased riverbed degradation and river depth on aquatic organisms are unknown, increased sediment load could have adverse effects, directly by smothering the organisms and indirectly by changing the bottom geometry and bottom sediments, which could in turn alter current patterns and velocities. Short-term increases in turbidity above ambient concentrations probably result during bank preparation and revetment placement activities. However, once the river's banks are stabilized, rates of erosion diminish and, consequently, these areas undoubtedly contribute less turbidity than do unprotected eroding banklines.

256. Essentially, the ecology of revetments has never been investigated, although WES is currently coordinating some studies in this area. Presently, while it is felt that some revetment types may provide habitat for aquatic organisms, changes have occurred in abundances and composition of the river's biota and in productivity of revetment areas; these changes should be studied.

PART VIII: RECOMMENDED AREAS OF RESEARCH

257. The overall results of this study indicate the need for new or more intensive research in the existing system. This section considers several of the major research areas. There are, however, many additional research areas worthy of study.

Dredging and Disposal Operations

258. Much of the environmental concern associated with maintenance dredging and disposal operations is related to the destruction of benthic communities that are considered to play an important role in the river's ecology. Those organisms inhabiting the main river channel may be directly destroyed by dredging or may be smothered through the disposal of dredged material. In the study reach, however, little data are available that allow evaluation of the effects of dredging and disposal operations on benthic communities.

259. Twelve dredged sites, 15 open-water disposal sites, and 3 river border sites in the Middle Mississippi River area were surveyed by WES in 1973;[37] the survey did not include any sites in an undredged part of the main channel. This limited study indicated that generally the abundances and diversity of benthic organisms were lower at the dredged sites than at the disposal sites or in the river border areas and were lower at the disposal site than in the river border area.

260. Areas in the river that have not been affected by dredging and disposal operations need to be surveyed and evaluated along with data acquired from dredged and disposal areas in order to determine if maintenance activities contribute to the low numbers and diversity of benthic organisms observed during the WES survey. It is very possible that bottom conditions in the undisturbed main river channel limit even moderate benthic colonization. The potential direct destruction of benthic organisms is probably greater at disposal locations; however, this also requires further study.

Dikes

261. In addition to the more than 800 dikes now existing in the Middle Mississippi River, dike fields are continually being constructed to obtain a 9-ft channel. Although physical model studies at CSU have contributed to the understanding of how dikes affect river morphology and behavior, the effects of dikes on the river's ecology have not been studied.

262. Dikes are characteristic features of both the main river and many of the side channels. Some of the dikes occurring in side channels were once part of the main river and now are only remnants of what were once dike fields. Many of the dikes found in side channels were placed to retard flow at low discharges and to pass flow at high discharges. By retarding flow at low discharges, water is diverted to the main channel to help maintain the navigation channel. There are several questions yet to be answered that are related to the effects that dikes in the main channel and in side channels have on aquatic organisms.

263. In the main river, dikes projecting from the banks provide slack-water areas on the downstream side and part of the upstream side during low flow. These slack-water conditions appear to provide additional habitat diversity for fish and other aquatic organisms not found in the main channel. Currently, there are approximately 91 miles of dikes in the Middle Mississippi River; new dikes are continually being constructed and old dikes extended. Studies aimed at assessing the importance of slack-water areas as resting, feeding, and reproduction sites for fish and other aquatic organisms need to be undertaken.

264. In addition to providing slack-water areas, the rocks from which dikes are constructed provide areas for the colonization of benthic organisms and consequently become primary areas of origin for drift organisms. The actual drift component, which is determined in part by increased flows and life cycles of benthic organisms, is directly utilized as a food source for fish. Generally, the larger the stones and the more complex the substratum, the more diverse is the benthic

fauna.[31] However, because of fluctuating water levels, colonization of dikes in the Middle Mississippi River may be limited to only certain benthic organisms. The extent and diversity of colonization on dikes by benthic organisms and their contribution to the drift component are other areas in need of study.

Revetments

265. To aid in maintaining a navigation channel, the Corps has protected certain critical banks with revetments to prevent erosion. Essentially nothing is presently known about the effects of revetment on the river's flora and fauna. When a bankline is revetted, changes in the abundance and composition of the river's biota and in the secondary productivity of these areas are likely to occur. Preliminary surveys of a few revetted areas in the Middle Mississippi River by WES indicate that these areas are capable of providing additional habitat diversity for aquatic organisms and, therefore, may be beneficial. It is probable that the design of revetments could considerably alter their effect on the biota. A particular design for revetments may provide a more diverse habitat for aquatic organisms than others; if not, such a design could possibly be developed. It seems important to attempt to recognize variations in revetment works that might result in a significant difference in the type of habitat provided.

Side Channels

266. If it is decided that side channels are important features to the ecology of the river, improvement and/or maintenance of these areas as habitat for riverine organisms is a justifiable goal. "Which side channels should be maintained or improved?" or "What modifications of methods can be used to maintain these areas effectively?" are seemingly simple questions involving complex problems in need of solution.

267. Side channels exist under extremely variable conditions. Some are located on the inside of bends, some on the outside of bends, others in straight stretches of the river. Each side channel is affected differently by the geometry of the main river to which it is

connected and by fluctuating flow regimes. The positions of the entrances and exits vary among side channels; some have multiple entrances and exits. Most side channels in the Middle Mississippi River have internal dikes, varying in height, structure, and position, that affect the flow of water through the channel depending on the river stage.

268. It is generally agreed that the complexity of the problem does not lend itself to simple solution. Decisions relevant to which side channels should be maintained and/or improved and what modifications could be used to accomplish this require extensive field studies aimed at assessing the nature of each side channel in question and thorough model studies based on complete prototype data for a given situation.

269. Since extensive data have been collected from 23 side channels in the Middle Mississippi River, it seems reasonable to use this information as a data base to aid in solving specific problems.

270. One approach would be first to initiate laboratory model studies designed to evaluate methods of maintaining and/or improving <u>specific</u> side channels, or perhaps a selected group of side channels sharing some important attribute, since it would not be economically feasible to perform model studies for every side channel. Not all side channels are equally important from a biological point of view as shown by their ranks using several biological characteristics (Part VI). Once ranked, side channels could be grouped according to some physical characteristic (i.e., those closed off at the entrances, those closed off at the exits, and those having internal dikes of higher elevation). Model studies could then be performed using one or more of those side channels ranked highest in one group (i.e., those whose entrances are closed off) and one or more of those having lowest rank in another group (i.e., those whose exits are closed off). Once the behavior of the highest ranked side channels is understood, those side channels having the lowest ranks could be restructured to simulate conditions of the former.

271. Such a procedure, based on prototype studies, would provide answers to questions concerning what modifications could be used and

how to use them effectively to improve a side channel. Optimum results can be achieved only through the extension of such physical model studies to a field situation. In other words, field application would be required to assess the impact of restructuring a side channel on the biotic communities within a particular side channel.

272. Internal dikes within side channels have both favorable and unfavorable effects on aquatic communities. By reducing or eliminating the flow of water through a particular reach of the side channel, the dikes create more stable or slack-water conditions favoring lentic-adapted species. Reduced flow normally reduces turbidity, which in turn may favor the growth of the primary producers and other components of the food chain. However, internal dikes are essentially physical barriers during low flow and most likely limit the movement of organisms (i.e., fish) that use both side channels and the main river during their life cycles. Additionally, internal dikes are associated with increasing rates of sedimentation during high flows and thus may reduce the longevity of a particular side channel.

273. While the outlook for preserving side channels by designing suitable structures in the dike fields of the main river is not good, removal, alteration, and repositioning of existing dikes within side channels could prove beneficial to maintaining and/or improving the biological habitat of side channels. It may be desirable to remove or alter certain dikes by notching them, which would (a) provide for the free movement of aquatic organisms between the side channel and the main river and (b) allow flow to pass through the side channel and possibly extend the life of the channel or improve the water quality. Repositioning of dikes, although costly, may provide another method of increasing the longevity of side channels.

274. Laboratory model studies could be useful in assessing the changes in side channels caused by removing certain internal dikes, the repositioning of others, or notching existing dikes in a particular side channel of interest. The results from the model studies could then be applied to corresponding field situations.

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Table 1

Comparison of Numbers of Taxa Found by Missouri Department of Conservation[29] with Those Found by the Waterways Experiment Station[30]

		Number of Taxa				
Agency	Biological Group	Total for Side Channel	Restricted to Side Channel Only	Total for River Border Area	Restricted to River Border Area Only	Total
MDC*	Phytoplankton	35	9	32	6	41
	Zooplankton	34	11	28	5	39
	Benthos	55	22	67	34	89
	Fish	46	8	46	8	54
	Total	170	50	173	53	223
WES**	Phytoplankton	62	39	28	5	67
	Zooplankton	23	7	16	0	23
	Benthos	55	32	31	8	63
	Fish	52	23	29	0	52
	Total	192	101	104	13	205

* Missouri Department of Conservation sampled three side channels and three river border areas.
** Waterways Experiment Station sampled 23 side channels and 4 river border areas.

Table 2

Results of Analyses of Variance for Side Channels and Stations for Each Sampling Period

Variable	Sampling Period I			Sampling Period II			Sampling Period III		
	Side Channel*	Station**	Side Channel†	Side Channel*	Station**	Side Channel†	Side Channel*	Station**	Side Channel†
Physicochemical									
Surface									
Temperature (°C)	X††	X	X	X		X	X		X
Dissolved oxygen (mg/ℓ)	X		X	X		X	X		X
Turbidity (JTU's)	X		X	X		X	X		X
pH	X	X	X	X		X	X		X
Alkalinity (mg/ℓ)	X		X	X		X	X		X
Bottom									
Temperature (°C)	X		X	X		X	X		X
Dissolved oxygen (mg/ℓ)	X		X	X		X	X		X
Turbidity (JTU's)	X		X	X		X	X		X
pH	X		X	X		X	X		X
Alkalinity (mg/ℓ)	X		X	X		X	X	X	X
Benthic Organisms									
Total No./0.16 m^2	ns‡	ns	ns	X		X	X		X
No./m^2	ns	ns	ns	X		X	X		X
No. of taxa	ns	ns	ns	X		X			
Diversity ($\bar{d}$)	ns	ns	ns	X		X	X		
Evenness (e)	ns	ns	ns	X		X			
Insecta (No./0.16 m^2)	ns	ns	ns	X		X			
Oligochaeta (No./0.16 m^2)	ns	ns	ns	X		X			
Hirudinea (No./0.16 m^2)	ns	ns	ns						
Crustacea (No./0.16 m^2)	ns	ns	ns	X		X			
Pelecypoda (No./0.16 m^2)	ns	ns	ns						
Gastropoda (No./0.16 m^2)	ns	ns	ns						
Phytoplankton									
Diversity ($\bar{d}$)	X								
Evenness (e)	X		X						
Chlorophyta (No./ℓ)	X		X				X		X
Euglenophyta (No./ℓ)	X		X	X		X	X		
Chrysophyta (No./ℓ)	X		X				X		X
Cyanophyta (No./ℓ)	X		X	X		X			
Cryphophyta (No./ℓ)	X		X						
Total No./ℓ	X		X	X		X	X		X
Zooplankton									
Diversity ($\bar{d}$)	X		X				X	X	X
Evenness (e)						X		X	
Cladocera (No./ℓ)	X		X						
Copepoda	X	X							
Rotifera (adults) (No./ℓ)	X		X	X		X	X		
Rotifera (eggs) (No./ℓ)	X		X				X	X	X
Protozoa (No./ℓ)	X		X	X		X			
Total No./ℓ	X		X	X		X			
Fish (per 6 Seine Hauls)									
Total fish	ns	ns	ns	X		X	X		X
Total young-of-year (y-o-y)	ns	ns	ns				X		X
Total adult/juvenile (A/J)	ns	ns	ns		X	X			
Diversity ($\bar{d}$)	ns	ns	ns						
Evenness (e)	ns	ns	ns						
No. of commercial	ns	ns	ns	X		X	X		X
No. of forage	ns	ns	ns	X		X	X		X
No. of predator	ns	ns	ns				X	X	X
No. of sport	ns	ns	ns	X		X	X		X
No. of commercial y-o-y	ns	ns	ns	X		X	X		X
No. of forage y-o-y	ns	ns	ns				X		X
No. of predator y-o-y	ns	ns	ns				X	X	X
No. of sport y-o-y	ns	ns	ns	X		X	X		X
No. of commercial A/J	ns	ns	ns						
No. of forage A/J	ns	ns	ns	X		X			
No. of predator A/J	ns	ns	ns						
No. of sport A/J	ns	ns	ns	X		X			
No. of taxa			X	X	X	X		X	

* One-way AOV for differences among side channels.
** Two-way AOV for differences among stations accounting for side channel differences.
† Two-way AOV for differences among side channels accounting for station differences.
†† X means significant at 5% level.
‡ ns means no sample.

Table 3

Analysis of Variance for Differences in Mean Number of Benthic Organisms for Primary and Secondary Substrate Classifications

Primary Substrate Classification				Secondary Substrate Classification			
Substrate Type	Number of Observations	$\overline{X}$ No. of Organisms	Significance ($P < 0.05$)*	Substrate Type	Number of Observations	$\overline{X}$ No. of Organisms	Significance ($P < 0.05$)
Sand	74	20.30	a	Sandy	51	19.43	a
				Silty sand	21	20.62	a
				Clayey sand	2	28.50	a
Clay	206	89.55	b	Clayey	116	115.39	a
				Silty clay	64	61.55	b
				Sandy clay	19	51.32	b
				Sandy, silty clay	7	21.39	b
Silt	47	79.57	b	Silty	6	36.83	a
				Sandy silt	27	67.07	a
				Sandy, clayey silt	8	159.35	b
				Clayey silt	6	72.33	ab

* Any two means followed by the same letter are not significantly different by least significant difference (LSD).

Table 4

Mean Difference (Side Channel Minus River Border Area) and Significance by Paired T-Test

Characteristics of Fish Collection Made During Sampling Period II

Variable		Mean Differences: Overall Side Channel $\overline{X}$ vs River Border Area Observation	Mean Differences: Side Channel Station Observation vs River Border Area Observation: Station 1	Station 2	Station 3
Total fish		63*	46*	95*	48*
Total young-of-year		66*	48*	95*	55
Total adult/juvenile		-3	<-1	<-1	<-7
Species diversity $\overline{d}$		0.93*	0.88*	0.86*	1.02*
Evenness index e		0.17*	0.18*	0.14	0.19*
Young-of-year:	commercial	2*	2*	3*	1*
	forage	40*	30*	55*	35*
	predator	1	0	0	0
	sport	24*	15*	36*	22*
Adult/juvenile:	commercial	<1*	<1	<1*	1
	forage	-4	-1	-1	-9
	predator	<1	<1	<1	<1
	sport	<1*	<1	<1*	<1
Number of taxa		4*	3*	4*	4*

Note: Numbers per six seine hauls.
* $P < 0.05$.

Table 5

Overall Mean Differences (Side Channel Minus River Border Area) and Significance for Physicochemical and Biological Variables Based on Collections During Sampling Period III

Type	Measurements (Units)	Overall Mean Differences
Physicochemical-surface	Temperature (°C)	2.0
	Dissolved oxygen (mg/ℓ)	3.3*
	Turbidity (JTU's)	-185.3*
	pH	0.2*
	Total alkalinity (mg/ℓ)	43.2*
Physicochemical-bottom	Temperature (°C)	0.0
	Dissolved oxygen (mg/ℓ)	-0.60*
	Turbidity (JTU's)	-205.8*
	pH	0.2*
	Total alkalinity (mg/ℓ)	54.7*
Benthic organisms	Total No. (No./0.18 m^2)	55.5*
	(No./m^2)	99.5*
	No. of taxa	1.3
	Species diversity $\bar{d}$	0.03
	Evenness index e	0.06
	Insecta (No./0.16 m^2)	19.0
	Oligochaeta (No./0.16 m^2)	35.0*
	Hirudinea (No./0.16 m^2)	0.3
	Crustacea (No./0.16 m^2)	0.08
	Pelecypoda (No./0.16 m^2)	1.3*
	Gastropoda (No./0.16 m^2)	0.08
Phytoplankton	Species diversity $\bar{d}$	-0.32
	Evenness index e	-0.06
	Chlorophyta (No./ℓ)	-30.0
	Euglenophyta (No./ℓ)	137.5
	Chrysophyta (No./ℓ)	-30.6
	Cyanophyta (No./ℓ)	1.2
	Cryptophyta (No./ℓ)	0.0
	Total No./ℓ	78.1
Zooplankton	Species diversity $\bar{d}$	0.32*
	Evenness index e	0.11
	Cladocera (No./ℓ)	2.3
	Copepoda (No./ℓ)	2.6
	Rotifera (adults) (No./ℓ)	0.4*
	Rotifera (eggs) (No./ℓ)	0.0
	Protozoa (No./ℓ)	-2.4
	Total No./ℓ	-0.9
Fish (per six seine hauls)	Total fish	14.1
	Total young-of-year	14.3
	Total adult/juvenile	-0.2
	Species diversity $\bar{d}$	0.25
	Evenness index e	0.15
	Young-of-year: commercial	19.3
	forage	7.1
	predator	0.7
	sport	-12.4
	Adult/juvenile: commercial	0.0
	forage	0.8
	predator	-0.08
	sport	-1.0
	Number of taxa	1.8

* Significant at 5% level.

Table 6

Tests for Significant Differences in Side Channels

Using Controlling Elevation as Variable

Mean Total Number	Sampling Period	Elevation ft	Mean	Standard Deviation	t-Value	Degrees of Freedom
Young-of-year	I	≥20	115.63	50.19	+1.46	16
		≤15	71.30	71.52		
		≥20	115.63	50.19	+2.71*	11
		>15 - <20	47.98	28.75		
		>15 - <20	47.98	29.75		
		≤15	71.30	71.52	-0.52	13
	II	≥20	184.0	136.73	+1.75	16
		≤15	100.39	58.02		
		≥20	184.0	136.73	+1.25	11
		>15 - <20	99.56	73.98		
		>15 - <20	99.56	73.98		13
		=15	100.39	58.02	-0.02	
Young-of-year species	I	≥20	5.05	1.14		16
		≤15	5.13	1.36	-0.12	
		≥20	5.05	1.14	+1.19	11
		>15 - <20	4.00	1.94		
		>15 - <20	4.00	1.94	+1.31	13
		=15	5.13	1.36		
	II	≥20	11.0	2.13	+2.86**	16
		≤15	7.55	1.66		
		≥20	11.0	2.13	+2.37	11
		>15 - <20	8.36	1.56		
Young-of-year sport fish	I	≥20	42.58	28.30	+2.66	16
		≤15	9.37	9.12		
		≥20	42.58	28.30	+1.58	11
		>15 - <20	14.26	12.27		
		>15 - <20	14.26	12.27	+0.87	13
		≤15	9.37	9.12		
	II	≥20	32.2	19.40	+2.78*	16
		≤15	11.73	13.29		
		≥20	32.2	19.40	+1.05	11
		>15 - <20	18.84	29.77		
		>15 - <20	18.94	29.77	0.87	
		≥15	11.73	13.29		

(Continued)

* Significant at the 5% level.
** Significant at the 1% level.

Table 6 (Concluded)

Mean Total Number	Sampling Period	Elevation ft	Mean	Standard Deviation	t-Value	Degrees of Freedom
Young-of-year sport species	I	≥20	1.55	0.49	+0.27	16
		≤15	1.45	0.90		
		≥20	1.55	0.49	+1.47	
		>15 - <20	1.00	0.86		
		≥15 - <20	1.00	0.86		
		≤15	1.45	0.90	-0.92	13
	II	≥20	4.92	1.26	+3.83**	16
		≤15	1.27	2.62		
		≥20	4.92	1.26	+2.24**	11
		>15 - <20	3.00	1.84		
		>15 - <20	3.00	1.84	0.47	13
		≤15	1.27	2.62		
Young-of-year forage fish	I	≥20	69.95	47.43	+0.94	16
		≤15	55.60	69.45		
		≥20	69.95	47.43	+1.54	11
		>15 - <20	32.62	32.07		
		>15 - <20	32.62	32.07		13
		≤15	55.60	69.45	-1.05	
	II	≥20	143.72	142.71	+1.51	16
		≤15	70.47	49.78		
		≥20	143.72	142.71	+1.10	11
		>15 - <20	60.70	39.71		
		>15 - <20	60.70	39.71		13
		≤15	70.47	49.78	-0.38	
Young-of-year forage species	I	≥20	3.06	0.69	+0.12	16
		≤15	3.01	0.97		
		≥20	3.06	0.69	+0.54	11
		>15 - <20	2.74	1.44		
		>15 - <20	2.74	1.44		
		≤15	3.01	0.97	-0.43	13
	II	≥20	4.37	0.77	+1.12	16
		≤15	3.78	1.31		
		≥20	4.37	0.77	+1.70	11
		>15 - <20	3.40	1.31		
		>15 - <20	3.40	1.31		13
		≤15	3.78	1.31	-0.52	

* Significant at the 5% level.
** Significant at the 1% level.

Table 7

Tests for Significant Differences Between

≥17.5 Side Channel Group and <17.5 Group

Mean Total Number	Sampling Period	Elevation ft	Mean	Standard Deviation	t-Value	Degrees of Freedom
Young-of-year	I	≥17.5	109.56	53.59	2.20*	23
		<17.5	57.6	60.10		
	II	≥17.5	102.65	115.49	0.23	23
		<17.5	90.56	52.98		
Young-of-year species	I	≥17.5	4.93	1.51	0.23	23
		<17.5	4.78	1.54		
	II	≥17.5	10.65	2.23	3.81**	23
		<17.5	7.82	1.49		
Young-of-year sport fish	I	≥17.5	33.33	41.25	2.34*	23
		<17.5	7.97	8.45		
	II	≥17.5	25.51	24.30	2.36*	23
		<17.5	9.50	11.22		
Young-of-year sport species	I	≥17.5	1.50	0.50	0.76	23
		<17.5	1.26	0.87		
	II	≥17.5	4.80	1.42	4.32**	23
		<17.5	2.59	1.12		
Young-of-year forage fish	I	≥17.5	29.95	44.29	-1.05	23
		<17.5	48.36	59.09		
	II	≥17.5	62.25	103.83		
		<17.5	65.78	44.79	-0.12	23
Young-of-year forage species	I	≥17.5	2.73	0.98		
		<17.5	2.98	1.17	-0.58	23
	II	≥17.5	4.07	1.03	0.38	23
		<17.5	3.88	1.23		

* Significant at the 5% level.

** Significant at the 1% level.

Table 8

Selected Fish Species Occurring in Side Channels Grouped According to Primary Preference

Habitat Preference Classification	Species
Lentic	Longnose gar Shortnose gar Bigmouth buffalo Smallmouth buffalo Mosquito fish Largemouth bass Bluegill White crappie Black crappie
Lotic	Threadfin shad Skipjack herring Bluntnose minnow Bullhead minnow Emerald shiner Brook silversides Channel catfish Spotted bass Sauger Goldeye Smallmouth bass
Ubiquitous	White bass Gizzard shad Golden shiner Western silvery minnow Blackstriped topminnow Freshwater drum Yellow bullhead Green sunfish Orange spotted sunfish Longear sunfish Warmouth Carp Red shiner Silver chub

Table 9

Habitat Preferences as a Function of Controlling Elevation

Habitat Preferences	Sampling Period	Elevation ft	Mean	Standard Deviation	t-Value	Degrees of Freedom
Ubiquitous, numbers	I	≥17.5	24.20	28.06	0.09	23
		<17.5	23.29	22.17		
	II	≥17.5	140.98	120.52	1.86	23
		<17.5	77.18	47.25		
Ubiquitous, species	I	≥17.5	1.36	0.57	-1.62	23
		<17.5	2.08	1.35		
	II	≥17.5	4.30	0.65	2.05	23
		<17.5	3.66	0.82		
Lotic, numbers	I	≥17.5	27.17	26.0	-0.10	23
		<17.5	47.46	24.40		
	II	≥17.5	6.40	4.02	1.27	23
		<17.5	4.31	3.97		
Lotic, species	I	≥17.5	1.04	0.49	-1.32	23
		<17.5	1.46	0.93		
	II	≥17.5	2.21	1.16	1.87	23
		<17.5	1.48	0.79		
Lentic, numbers	I	≥17.5	57.82	53.35	3.45**	23
		<17.5	11.23	13.53		
	II	≥17.5	35.69	28.07	3.76**	23
		<17.5	6.42	9.41		
Lentic, species	I	≥17.5	2.25	0.99	2.20*	23
		<17.5	1.40	0.89		
	II	≥17.5	3.34	0.89	4.12**	23
		<17.5	1.64	1.13		

** Significant at the 1% level.
 * Significant at the 5% level.

Table 10

Correlations of Biological Variables with Physical, Chemical, and Morphometric Variables

Variable Class	Benthic Organisms (Total No.)	Total Fish	Zooplankton No./ℓ	Phytoplankton No./ℓ
Physical				
Water temperature	-0.48** (106)	0.09 (102)	-0.02 (105)	-0.23 (156)
Turbidity	-0.17 (106)	-0.13 (102)	-0.05 (105)	0.02 (156)
Discharge	-0.19 (150)	-0.16 (82)	-0.17* (131)	-0.19* (131)
Chemical				
Dissolved oxygen	-0.28** (106)	-0.06 (102)	-0.05 (155)	0.07 (156)
pH	-0.43** (106)	0.01 (102)	0.07 (155)	-0.16** (156)
Total alkalinity	0.42 (106)	0.13 (102)	0.17* (155)	0.11 (156)
Morphometric				
Volume	-0.35** (141)	-0.16 (82)	-0.16 (123)	0.08 (125)
Area	0.22 (141)	0.16 (82)	0.28** (123)	0.02 (125)
Shoreline development	0.17 (141)	-0.18 (82)	-0.06 (12[illegible])	0.20* (125)

Note: The number of pairs of observations are in parentheses.
** Significant at 1% level.
* Significant at 5% level.

Table 11

Results of Multiple Regression Analyses Using Various Levels of Information to Estimate Selected Biological Dependent Variables

Dependent Variable	Class of Variable	Number of Observations	Independent Variables Included and Variation Explained by Each (%)	Variation Accounted for (%)	Cumulative Variation Explained (%)	Standard Error of the Estimate (Means)
Total benthic organisms	(1) Biological		Phytoplankton density (38)	41	41	
	(2) Biological + morphometric	57	As (1) plus surface area (6), volume (6)	12	53	23.2 (225.9)
	(3) Biological + morphometric + chemical		As (2) plus pH (16)	16	69	
Total fish	(1) Biological		Phytoplankton density (9)	9	9	
	(2) Biological + chemical	57	As (1) plus dissolved oxygen (8)	8	17	16.8 (116.5)
	(3) Biological + chemical + physical		As (2) plus turbidity (7)	7	24	
Forage fish	(1) Morphometric		Shoreline development (7)	7	7	
	(2) Morphometric + chemical	57	As (1) plus dissolved oxygen (5)	5	12	15.71 (90.8)
	(3) Morphometric + chemical + physical		As (2) plus turbidity (7)	7	19	
Sport fish	(1) Biological		Total benthic organisms (31), phytoplankton density (10)	41	41	
	(2) Biological + morphometric	57	As (1) plus surface area (14), volume (6)	20	61	3.2 (20.6)
	(3) Biological + morphometric + physical		As (2) plus turbidity (3)	3	64	
Zooplankton density	(1) Biological		Total benthic organisms (5)	5	5	
	(2) Biological + morphometric	57	As (1) plus shoreline development (4)	4	9	6.37 (54.4)
	(3) Biological + morphometric + chemical		As (2) plus dissolved oxygen (15)	15	24	
Phytoplankton density	(1) Biological	57	Total benthic organisms (24), zooplankton density (4), total fish (1)	29	29	45.61 (3138.5)
	(2) Biological + chemical	57	As (1) plus dissolved oxygen (38)	38	67	

Table 12

Linear Regression Equations to Estimate Selected Biological Dependent Variables

Dependent Variable y	Estimated Regression Equation
Total benthic organisms	y = 3539.73 - 433.0241 (pH) + 0.0266 (phytoplankton density) - 0.4385 (total fish) - 0.0651 (volume) + 0.1683 (surface area)
Total fish	y = 451.93 - 51.3244 (dissolved oxygen) - 0.2413 (turbidity) + 0.0101 (phytoplankton density)
Forage fish	y = 355.33 - 21.9238 (dissolved oxygen) - 0.2797 (turbidity) - 19.1180 (shoreline development)
Sport fish	y = 2.46 + 0.0465 (turbidity) + 0.0015 (total benthic organisms) + 0.0035 (phytoplankton density) - 0.0074 (volume) + 0.0380 (surface area)
Zooplankton density	y = 7.54 + 15.0854 (dissolved oxygen) + 0.0409 (total benthic organisms) - 14.8406 (zooplankton density) + 8.2189 (total fish)
Phytoplankton density	y = 12,373.06 + 2060.28 (dissolved oxygen) + 8.6539 (total benthic organisms) - 14.8406 (zooplankton density) + 8.2189 (total fish)

Table 13

Biological Groups and Subgroups for Which Information Was Used in Side Channel Rankings

Biological Group Subgroup	Sampling Period I	II	III
Fish			
Young-of-year (mean number/ six seine hauls)	NA*	23,13	23,13
Adult/juvenile (mean number/ six seine hauls)	NA	23,13	23,13
Sport fish (mean number/ six seine hauls)	NA	23,13	23,13
Forage fish (mean number/ six seine hauls)	NA	23,13	23,13
Total number (mean number/ six seine hauls)	NA	23,13	23,13
Diversity ($\overline{d}$)	NA	23,13	23,13
Phytoplankton			
Total density (mean number/ℓ)	23,** 13†	23,13	13
Diversity ($\overline{d}$)	23,13	23,13	13
Zooplankton			
Total density (mean number/ℓ)	23,13	23,13	13
Diversity ($\overline{d}$)	23,13	23,13	13
Benthos			
Insecta (mean number/0.16m^2)	NA	23,13	13
Oligochaeta (mean number/0.16 m^2)	NA	23,13	13
Pelecypoda (mean number/0.16 m^2)	NA	23,13	13
Total number (mean number/ 0.16 m^2)	NA	23,13	13
Diversity ($\overline{d}$)	NA	23,13	13

* NA - No information available.

** 23 - Information available and used for ranking all 23 side channels.

† 13 - Information available and used for ranking 13 side channels (1, 3, 6, 7, 10, 11, 12, 15, 16, 17, 19, 20, and 23).

Table 14

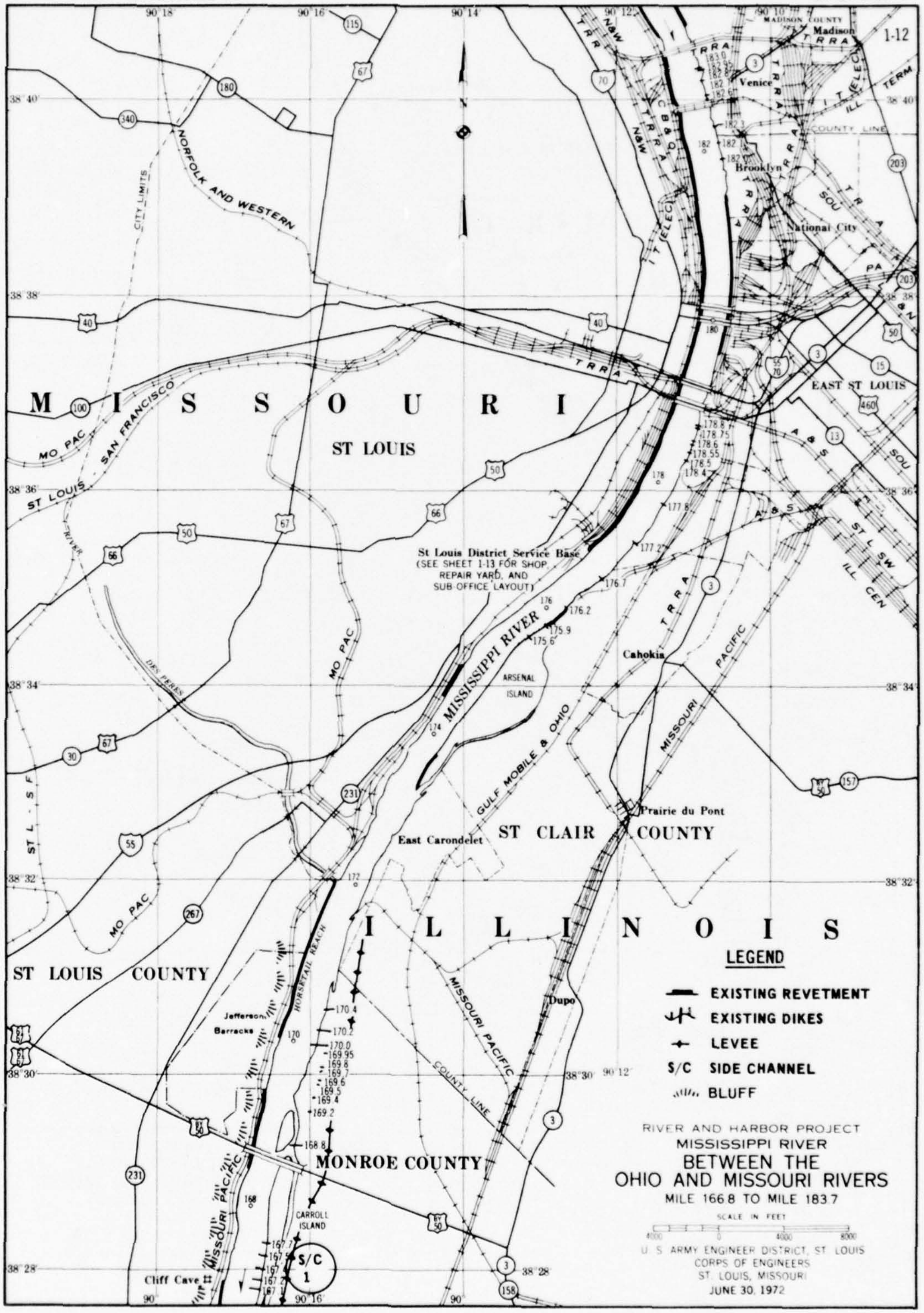
Biological Group and Overall Side Channel Rankings Based on Benthos, Fish, and Plankton (Zooplankton and Phytoplankton) for 23 Side Channels, Middle Mississippi River

Side Channel Identification	Benthos Rank Sampling Period II	Fish Rank Sampling Periods II & III	Plankton Rank Sampling Periods I & II	Sum of All Ranks	Overall Side Channel Rank
4	6	1	3	10	1
24	2	7	5	14	2
22	3	6	6	15	3
14	7	4	7	18	4
2	1	17	2	20	5
6	9	2	11	22	6
5	13	3	10	26	7
21	12	11	4	27	8
9	5	9	14	28	9
10	11	10	8	29	10
23	1	16	12	29	10
18	18	8	6	32	11
1	14	18	1	33	12
15	4	16	14	34	13
3	16	5	15	36	14
8	8	20	9	37	15
16	19	13	5	37	15
12	21	12	10	43	16
19	10	21	13	44	17
11	15	21	9	45	18
20	20	15	11	46	19
17	17	21	12	50	20
7	22	14	16	52	21

Table 15

Biological Group and Overall Side Channel Rankings Based on Benthos, Fish, and Plankton (Zooplankton and Phytoplankton) for 13 Side Channels, Middle Mississippi River

Side Channel Identification	Benthos Rank Sampling Periods II and III	Fish Rank Sampling Periods II and III	Plankton Rank Sampling Periods I, II, and III	Sum of All Ranks	Overall Side Channel Rank
10	2	3	4	9	1
6	5	1	3	9	1
3	5	2	5	12	2
16	6	5	2	13	3
23	1	8	5	14	4
15	2	8	7	17	5
1	7	9	1	17	5
12	9	4	8	21	6
11	3	10	9	22	7
19	4	10	9	23	8
17	9	10	6	25	9
20	8	7	10	25	9
7	10	6	11	27	10


1-12
MISSOURI
ST LOUIS
ST LOUIS COUNTY
ILLINOIS
ST CLAIR COUNTY
MONROE COUNTY
EAST ST LOUIS
Madison
Venice
Brooklyn
National City
Cahokia
Prairie du Pont
East Carondelet
Dupo
Jefferson Barracks
Cliff Cave
CARROLL ISLAND
ARSENAL ISLAND
MISSISSIPPI RIVER
HORSETAIL REACH
St Louis District Service Base
(SEE SHEET 1-13 FOR SHOP, REPAIR YARD, AND SUB-OFFICE LAYOUT)
NORFOLK AND WESTERN
SAN FRANCISCO
GULF MOBILE & OHIO
MISSOURI PACIFIC
COUNTY LINE
CITY LIMITS
DES PERES
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
S/C 1
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 166.8 TO MILE 183.7
SCALE IN FEET
4000 0 4000 8000
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1972

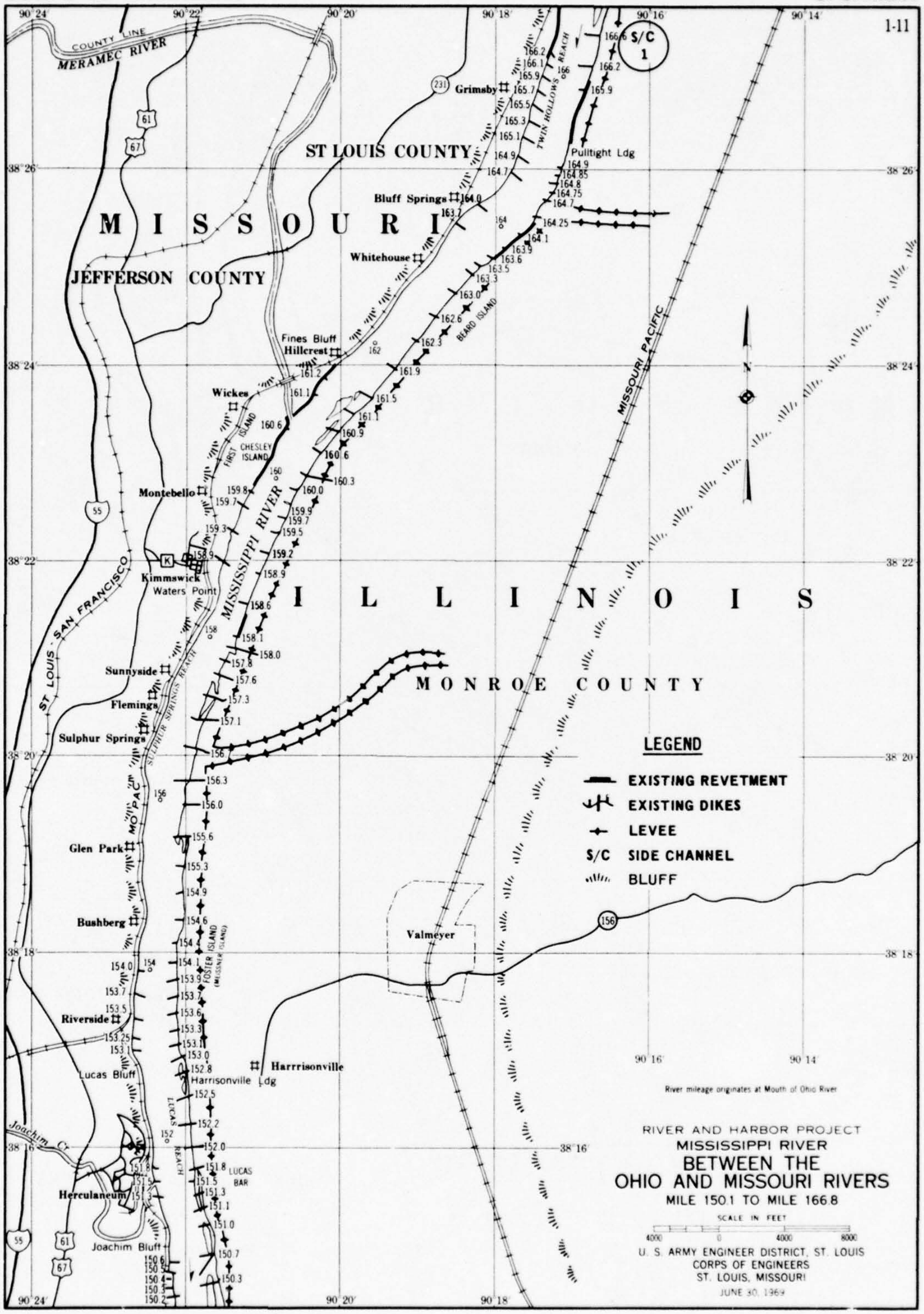
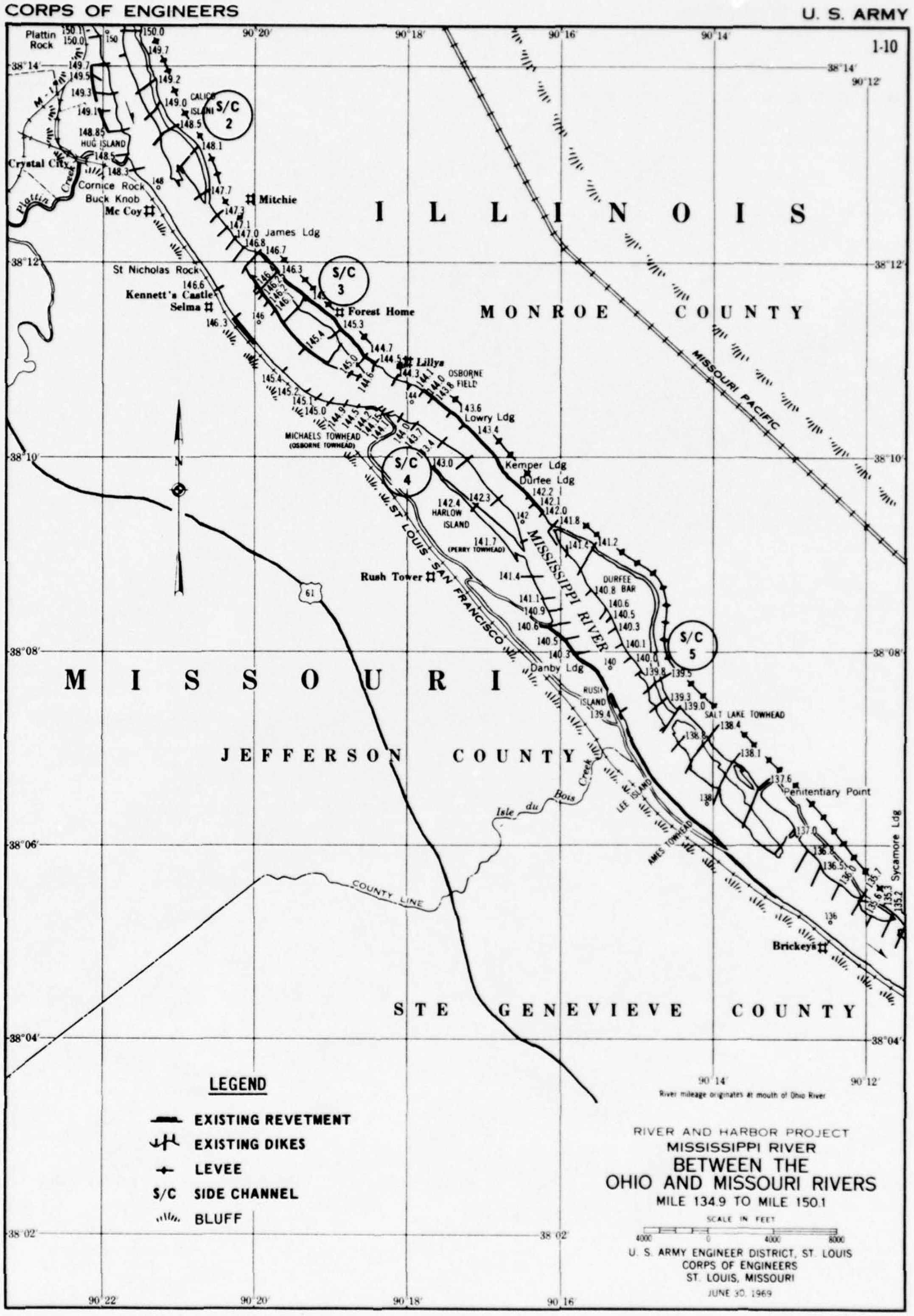

1-11
MISSOURI
ST LOUIS COUNTY
JEFFERSON COUNTY
ILLINOIS
MONROE COUNTY
MISSISSIPPI RIVER
MERAMEC RIVER
COUNTY LINE
MISSOURI PACIFIC
ST LOUIS - SAN FRANCISCO
MO PAC
TWIN HOLLOWS REACH
SULPHUR SPRINGS REACH
LUCAS REACH
BEARD ISLAND
FIRST ISLAND
CHESLEY ISLAND
FOSTER ISLAND (MEISSNER ISLAND)
LUCAS BAR
Grimsby
Pulltight Ldg
Bluff Springs
Whitehouse
Fines Bluff
Hillcrest
Wickes
Montebello
Kimmswick
Waters Point
Sunnyside
Flemings
Sulphur Springs
Glen Park
Bushberg
Riverside
Lucas Bluff
Harrisonville
Harrisonville Ldg
Valmeyer
Herculaneum
Joachim Cr.
Joachim Bluff
S/C 1
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at Mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 150.1 TO MILE 166.8
SCALE IN FEET
4000 0 4000 8000
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1969

PLATE 2


1-10
ILLINOIS
MONROE COUNTY
MISSOURI
JEFFERSON COUNTY
STE GENEVIEVE COUNTY
MISSISSIPPI RIVER
MISSOURI PACIFIC
ST LOUIS - SAN FRANCISCO
Plattin Rock
Crystal City
Cornice Rock
Buck Knob
Mc Coy
Mitchie
James Ldg
St Nicholas Rock
Kennett's Castle
Selma
Forest Home
Lillys
OSBORNE FIELD
Lowry Ldg
MICHAELS TOWHEAD (OSBORNE TOWHEAD)
Kemper Ldg
Durfee Ldg
HARLOW ISLAND
(PERRY TOWHEAD)
Rush Tower
DURFEE BAR
Danby Ldg
RUSH ISLAND
SALT LAKE TOWHEAD
Penitentiary Point
Sycamore Ldg
Brickeys
LEE ISLAND
AMES TOWHEAD
Isle du Bois Creek
COUNTY LINE
HUG ISLAND
CALICO ISLAND
S/C 2
S/C 3
S/C 4
S/C 5
River mileage originates at mouth of Ohio River
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 134.9 TO MILE 150.1
SCALE IN FEET
4000 0 4000 8000
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1969

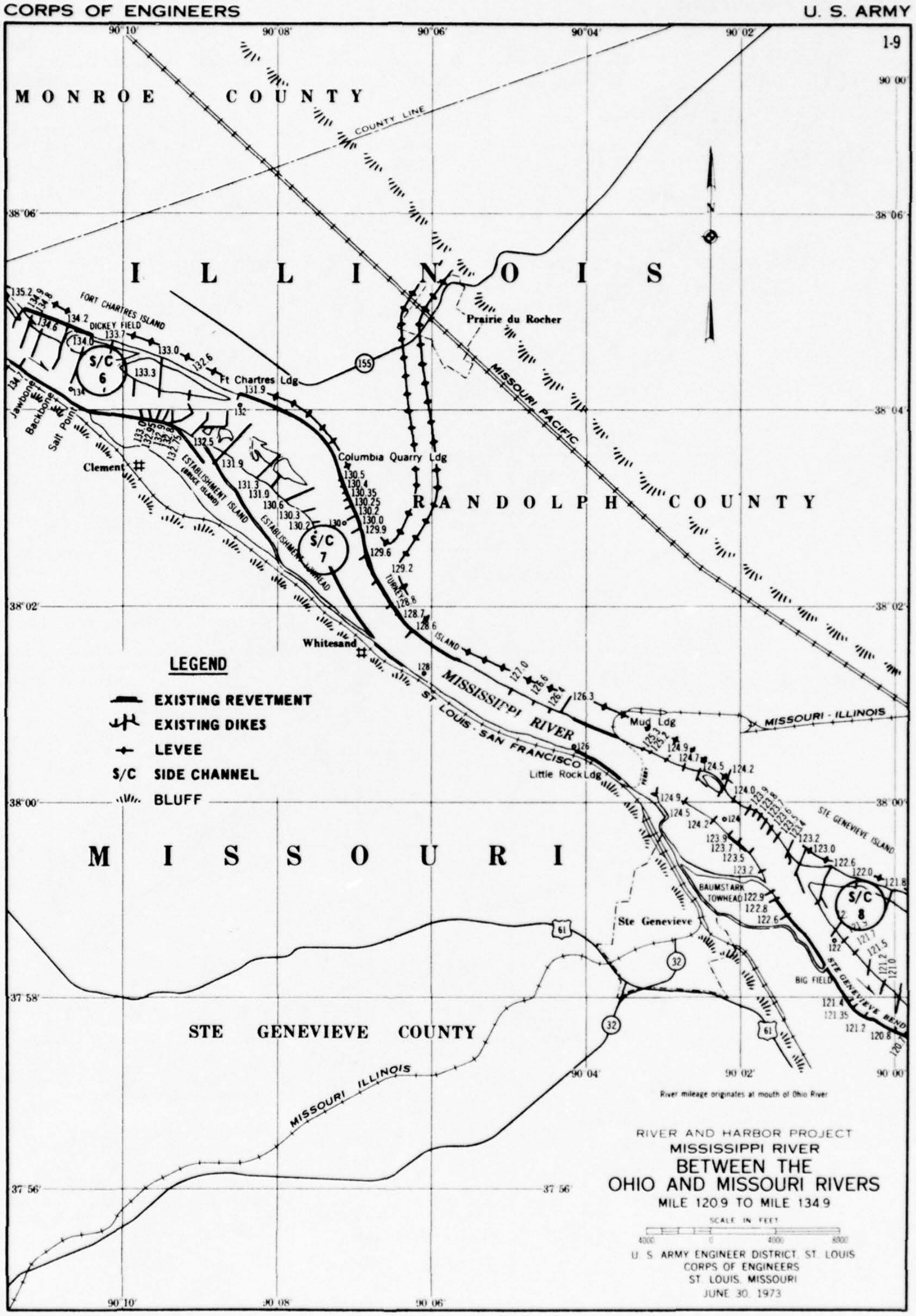
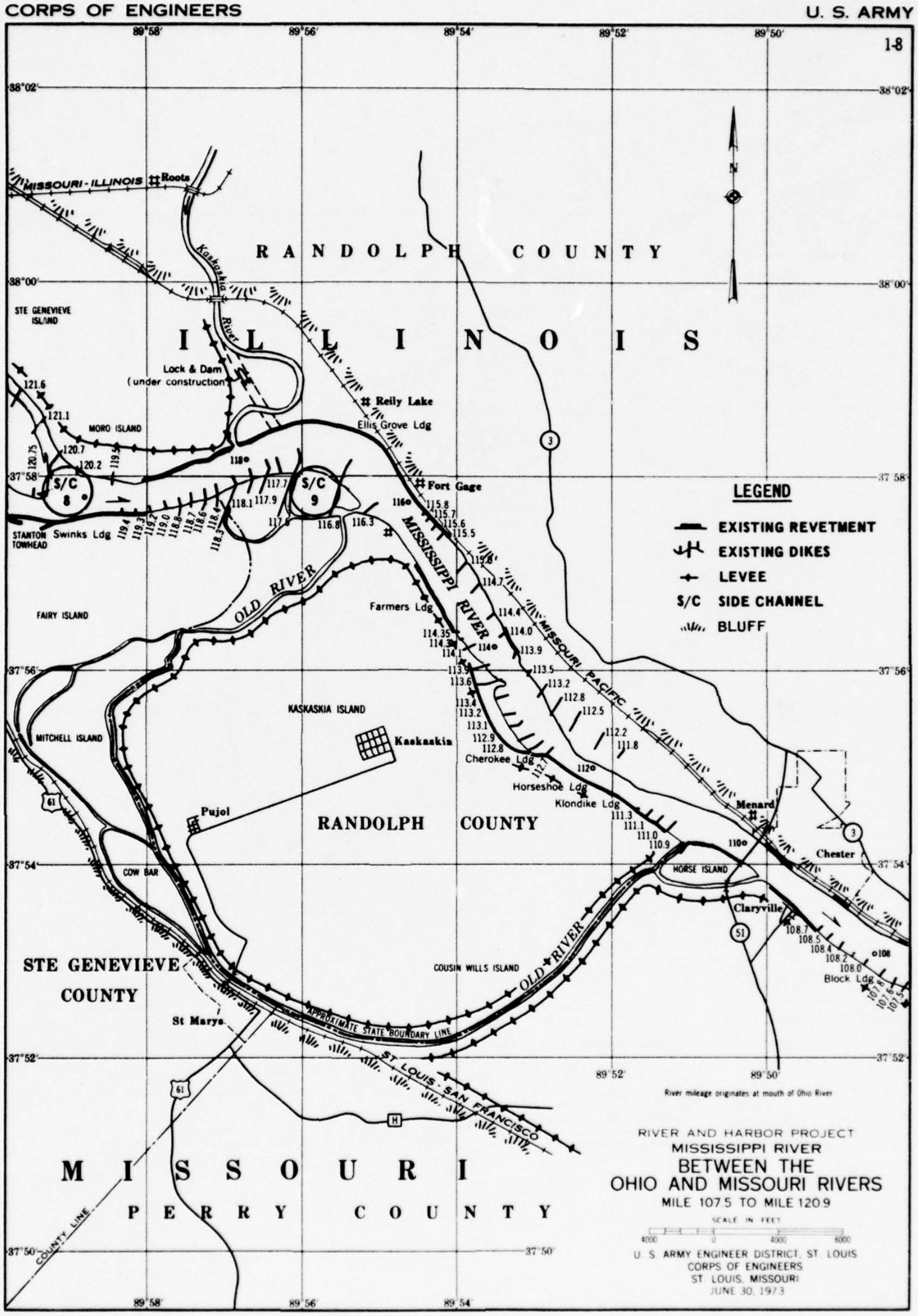

1-9
MONROE COUNTY
COUNTY LINE
ILLINOIS
RANDOLPH COUNTY
MISSOURI
STE GENEVIEVE COUNTY
FORT CHARTRES ISLAND
DICKEY FIELD
Ft Chartres Ldg
Prairie du Rocher
MISSOURI PACIFIC
Columbia Quarry Ldg
Jawbone
Backbone
Salt Point
Clement
ESTABLISHMENT ISLAND
Whitesand
MISSISSIPPI RIVER
ST LOUIS - SAN FRANCISCO
Mud Ldg
Little Rock Ldg
MISSOURI - ILLINOIS
STE GENEVIEVE ISLAND
BAUMSTARK TOWHEAD
Ste Genevieve
BIG FIELD
STE GENEVIEVE BEND
MISSOURI ILLINOIS
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 120.9 TO MILE 134.9
SCALE IN FEET
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1973

PLATE 4


1-8
RANDOLPH COUNTY
ILLINOIS
MISSOURI-ILLINOIS
Roots
Kaskaskia River
STE GENEVIEVE ISLAND
Lock & Dam (under construction)
Reily Lake
Ellis Grove Ldg
MORO ISLAND
Fort Gage
S/C 8
S/C 9
STANTON TOWHEAD
Swinks Ldg
MISSISSIPPI RIVER
OLD RIVER
MISSOURI PACIFIC
Farmers Ldg
FAIRY ISLAND
KASKASKIA ISLAND
Kaskaskia
MITCHELL ISLAND
Cherokee Ldg
Horseshoe Ldg
Klondike Ldg
Menard
Chester
Pujol
RANDOLPH COUNTY
COW BAR
HORSE ISLAND
Claryville
Block Ldg
COUSIN WILLS ISLAND
STE GENEVIEVE COUNTY
St Marys
APPROXIMATE STATE BOUNDARY LINE
ST LOUIS-SAN FRANCISCO
COUNTY LINE
MISSOURI
PERRY COUNTY
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 107.5 TO MILE 120.9
SCALE IN FEET
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1973

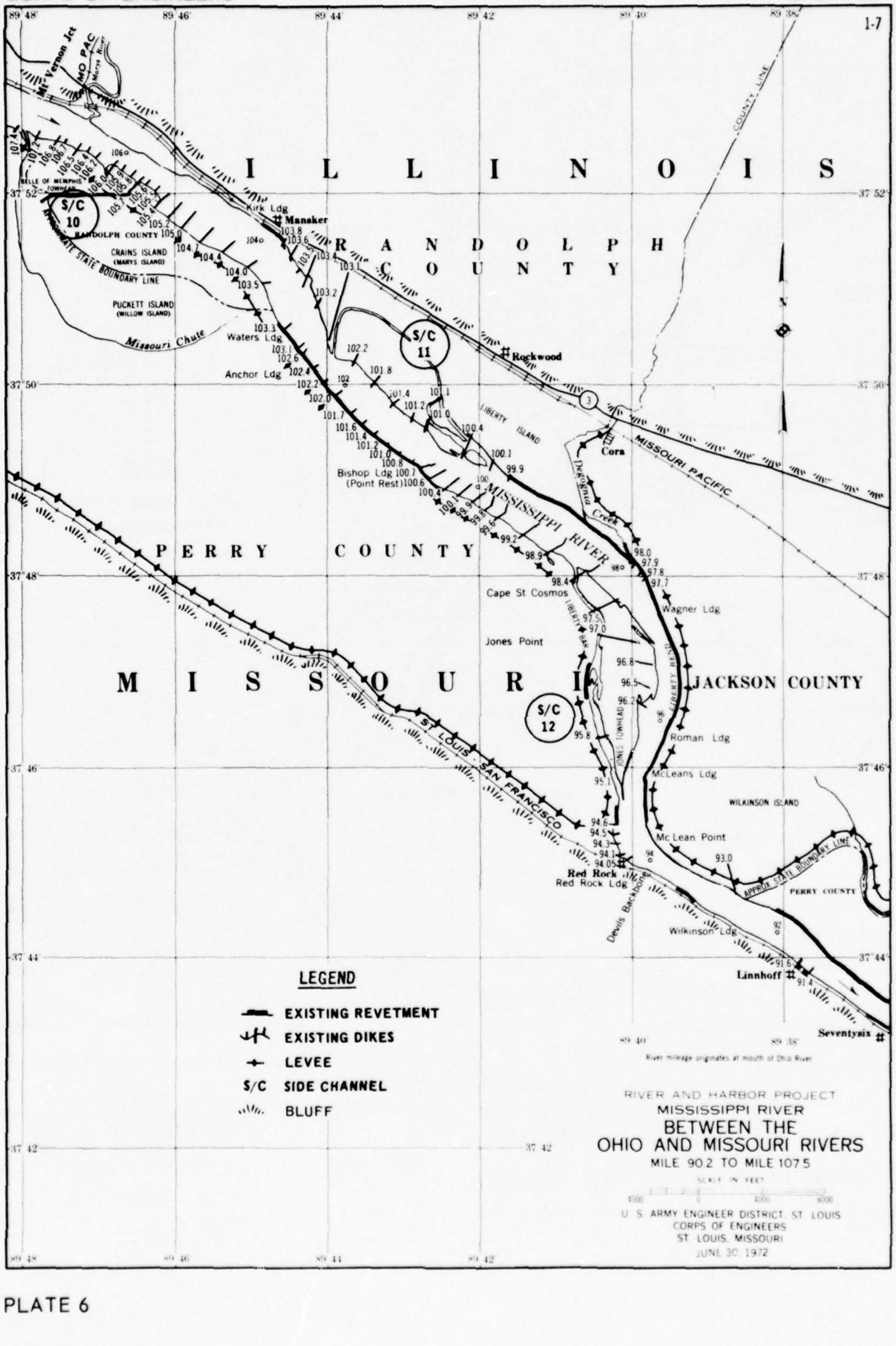
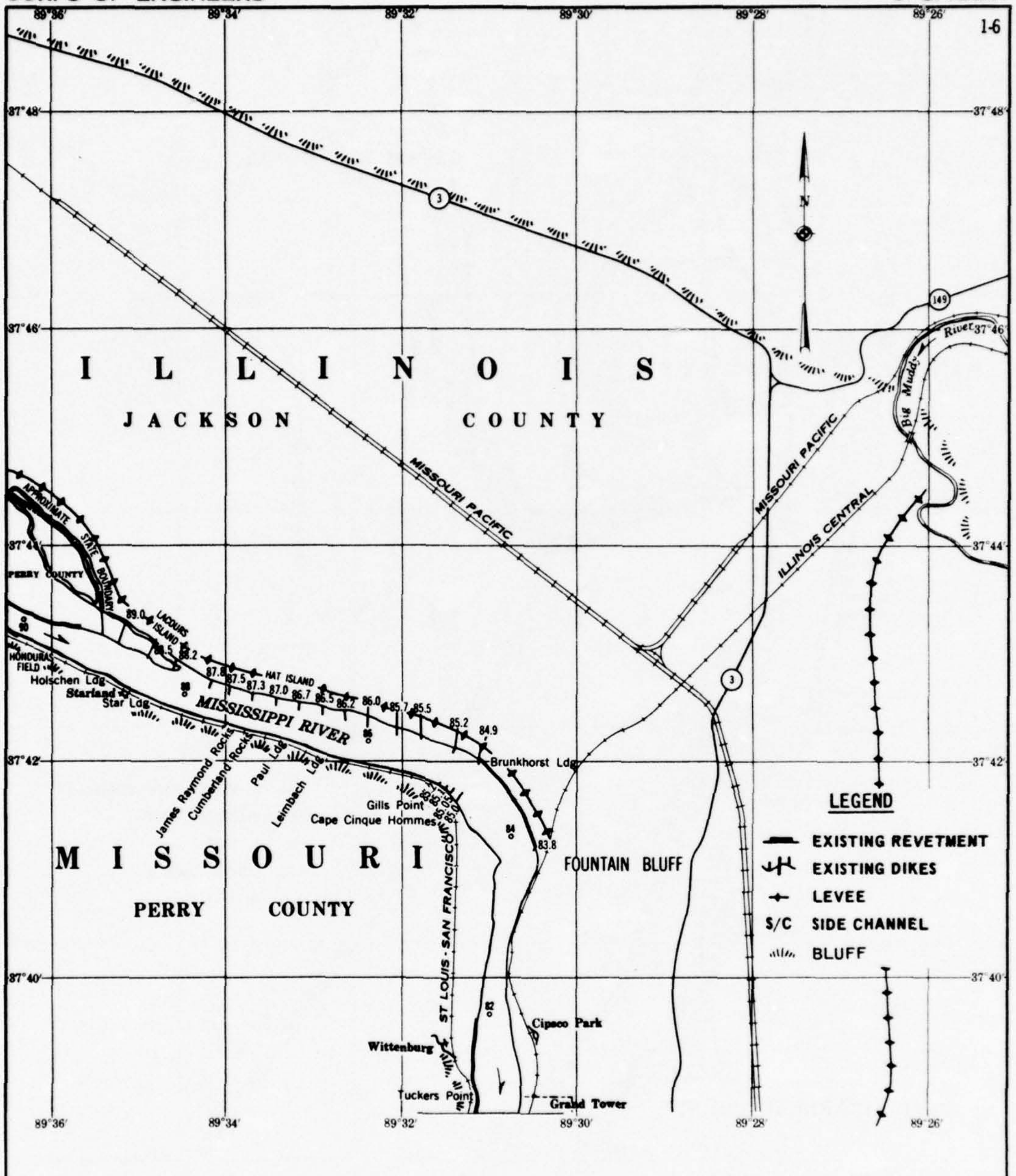

1-7
ILLINOIS
RANDOLPH COUNTY
PERRY COUNTY
MISSOURI
JACKSON COUNTY
MISSISSIPPI RIVER
MISSOURI PACIFIC
ST LOUIS - SAN FRANCISCO
COUNTY LINE
Mt Vernon Jct
MO PAC
Manaker
Kirk Ldg
Rockwood
Cora
Waters Ldg
Anchor Ldg
Bishop Ldg
(Point Rest)
Cape St Cosmos
Jones Point
Wagner Ldg
Roman Ldg
McLeans Ldg
Mc Lean Point
WILKINSON ISLAND
Red Rock
Red Rock Ldg
Devils Backbone
Wilkinson Ldg
Linnhoff
Seventysix
CRAINS ISLAND
(MARYS ISLAND)
PUCKETT ISLAND
(WILLOW ISLAND)
Missouri Chute
LIBERTY ISLAND
APPROX STATE BOUNDARY LINE
PERRY COUNTY
S/C 10
S/C 11
S/C 12
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 90.2 TO MILE 107.5
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1972

PLATE 6

CORPS OF ENGINEERS U. S. ARMY



River mileage originates at mouth of Ohio River

RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 80.9 TO MILE 90.2

SCALE IN FEET
4000 0 4000 8000

U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1969

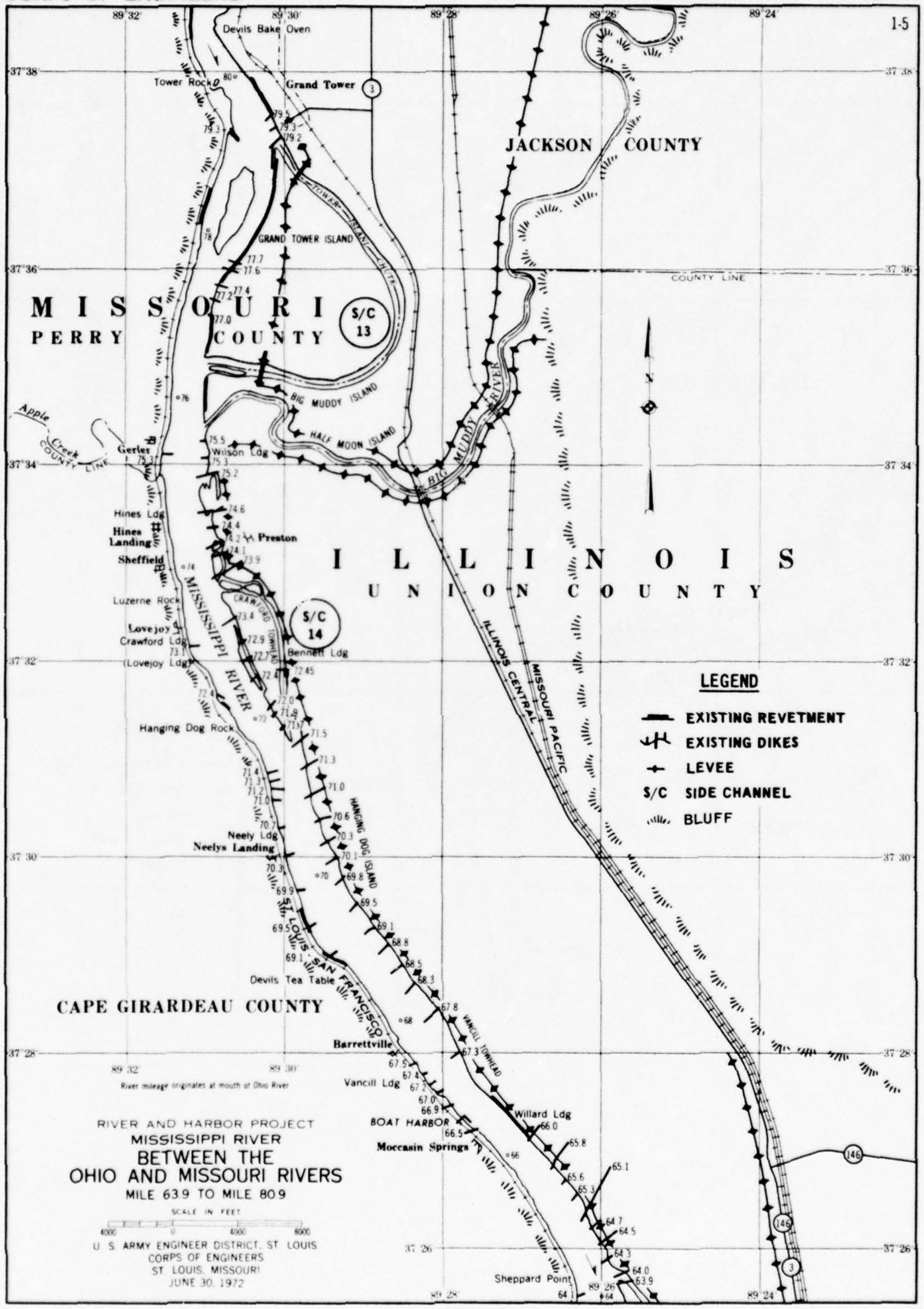
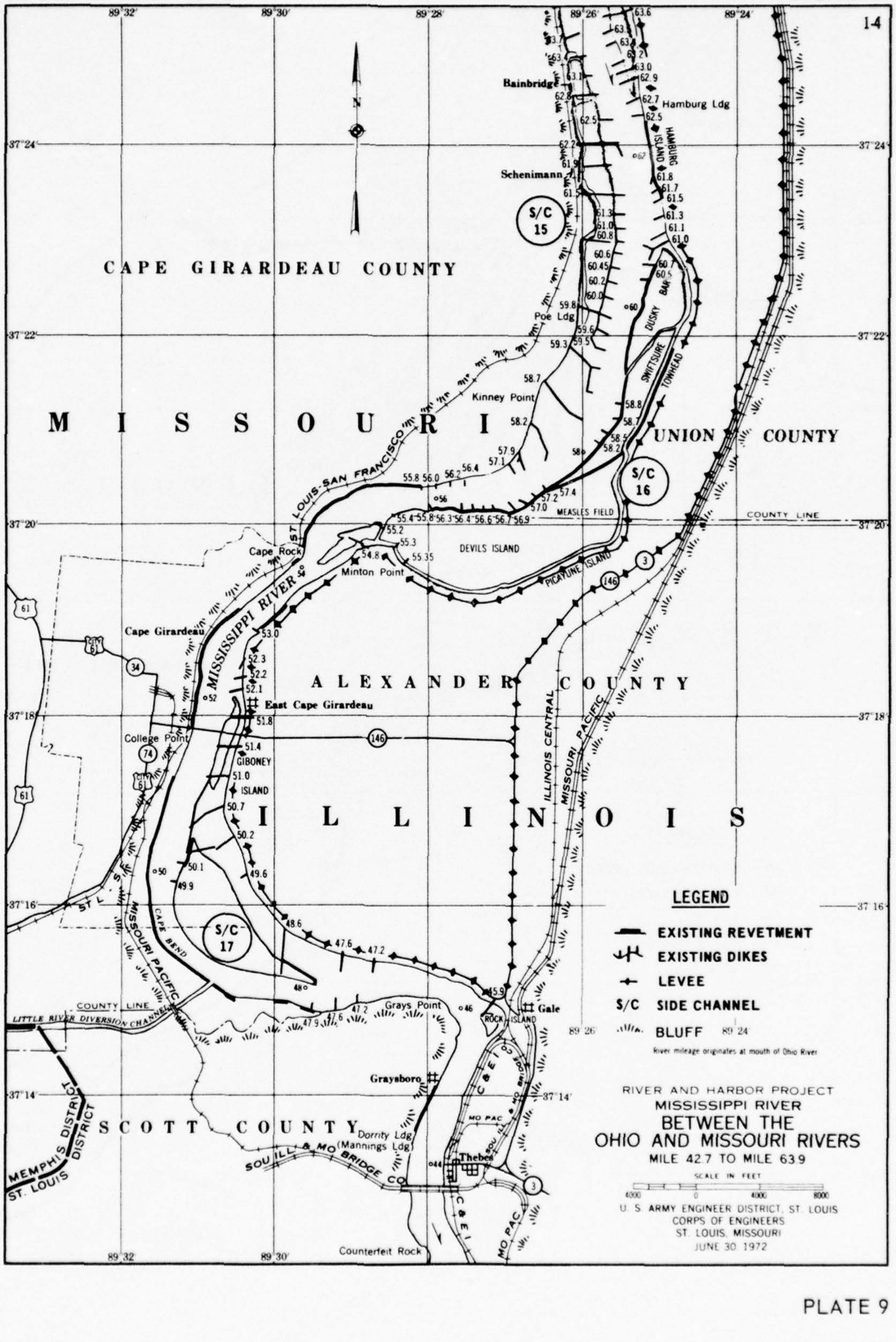

1-5
Devils Bake Oven
Tower Rock
Grand Tower
JACKSON COUNTY
GRAND TOWER ISLAND
MISSOURI
PERRY COUNTY
S/C 13
COUNTY LINE
BIG MUDDY ISLAND
HALF MOON ISLAND
BIG MUDDY RIVER
Apple Creek
COUNTY LINE
Gerler
Wilson Ldg
Hines Ldg
Hines Landing
Preston
Sheffield
ILLINOIS
UNION COUNTY
MISSISSIPPI RIVER
Luzerne Rock
S/C 14
Lovejoy
Crawford Ldg
(Lovejoy Ldg)
Bennett Ldg
ILLINOIS CENTRAL
MISSOURI PACIFIC
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
Hanging Dog Rock
HANGING DOG ISLAND
Neely Ldg
Neelys Landing
ST LOUIS SAN FRANCISCO
Devils Tea Table
CAPE GIRARDEAU COUNTY
Barrettville
Vancill Ldg
BOAT HARBOR
Willard Ldg
Moccasin Springs
Sheppard Point
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 63.9 TO MILE 80.9
SCALE IN FEET
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1972

PLATE 8


1-4
CAPE GIRARDEAU COUNTY
MISSOURI
UNION COUNTY
ALEXANDER COUNTY
ILLINOIS
SCOTT COUNTY
MISSISSIPPI RIVER
Bainbridge
Schenimann
Hamburg Ldg
Poe Ldg
Kinney Point
Cape Rock
Cape Girardeau
Minton Point
DEVILS ISLAND
MEASLES FIELD
COUNTY LINE
East Cape Girardeau
College Point
GIBONEY ISLAND
Grays Point
ROCK ISLAND
Gale
Graysboro
Dorrity Ldg (Mannings Ldg)
Thebes
Counterfeit Rock
S/C 15
S/C 16
S/C 17
LITTLE RIVER DIVERSION CHANNEL
MEMPHIS DISTRICT
ST. LOUIS DISTRICT
ST. LOUIS-SAN FRANCISCO
ILLINOIS CENTRAL
MISSOURI PACIFIC
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 42.7 TO MILE 63.9
SCALE IN FEET
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30 1972

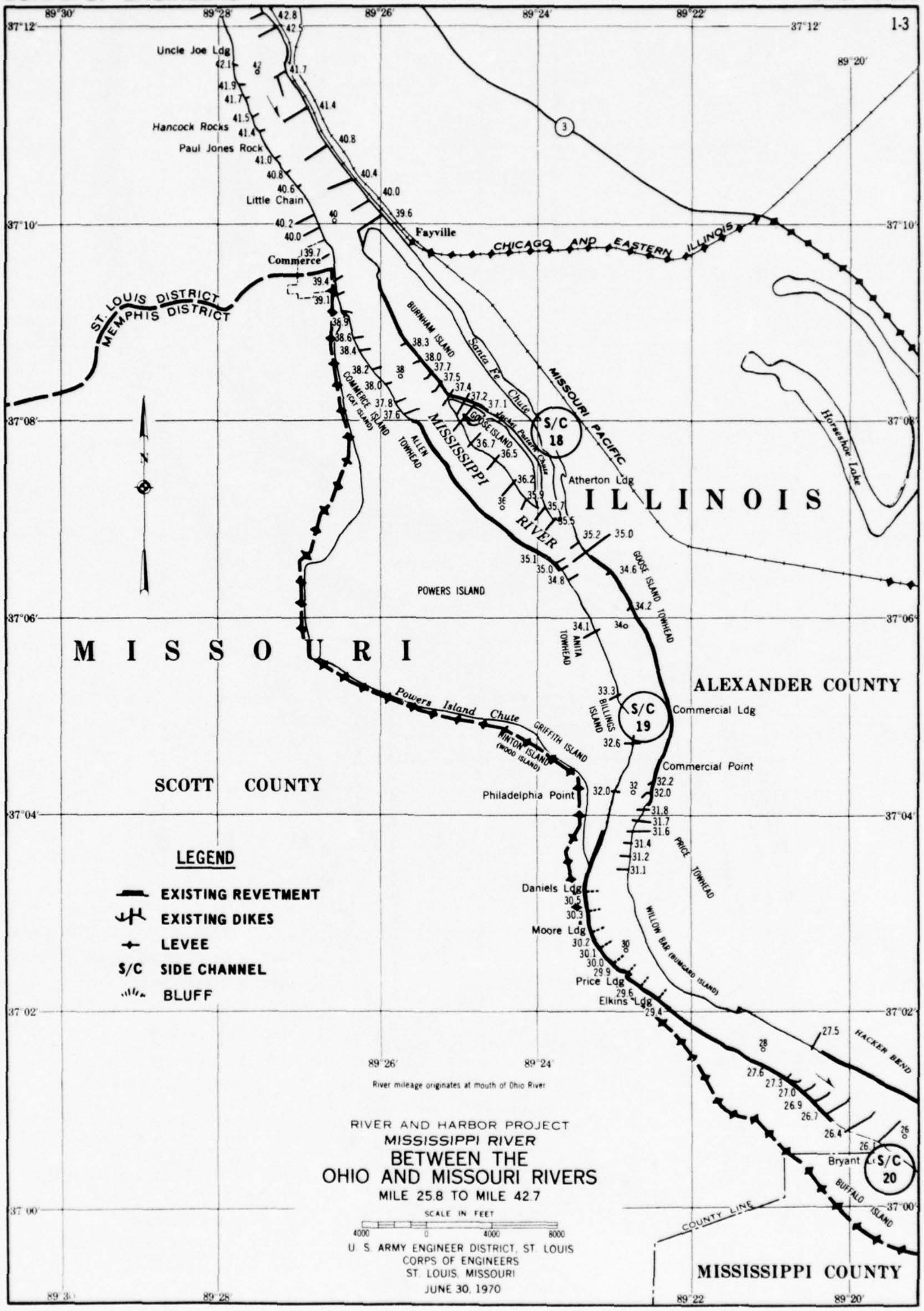
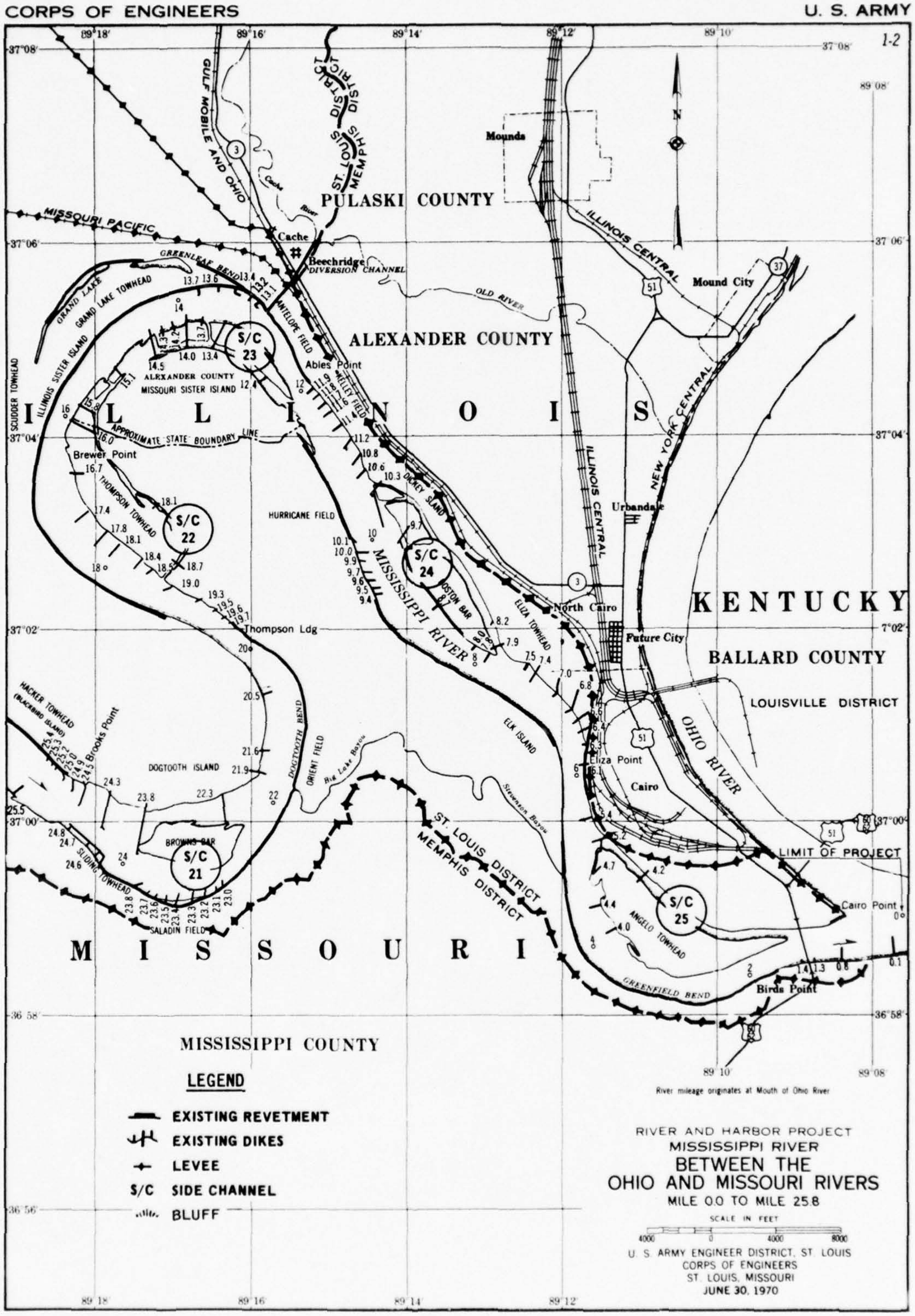

1-3
Uncle Joe Ldg
Hancock Rocks
Paul Jones Rock
Little Chain
Commerce
Fayville
CHICAGO AND EASTERN ILLINOIS
ST. LOUIS DISTRICT
MEMPHIS DISTRICT
BURNHAM ISLAND
Santa Fe Chute
MISSOURI PACIFIC
Horseshoe Lake
COMMERCE ISLAND
MISSISSIPPI RIVER
S/C 18
Atherton Ldg
ILLINOIS
POWERS ISLAND
GOOSE ISLAND TOWHEAD
ANITA TOWHEAD
MISSOURI
ALEXANDER COUNTY
BILLINGS ISLAND
S/C 19
Commercial Ldg
Powers Island Chute
GRIFFITH ISLAND
Commercial Point
SCOTT COUNTY
Philadelphia Point
PRICE TOWHEAD
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
Daniels Ldg
Moore Ldg
WILLOW BAR (BUMGARD ISLAND)
Price Ldg
Elkins Ldg
HACKER BEND
River mileage originates at mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 25.8 TO MILE 42.7
SCALE IN FEET
4000 0 4000 8000
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1970
Bryant
S/C 20
BUFFALO ISLAND
COUNTY LINE
MISSISSIPPI COUNTY

PLATE 10


1-2
PULASKI COUNTY
ALEXANDER COUNTY
ILLINOIS
KENTUCKY
BALLARD COUNTY
LOUISVILLE DISTRICT
MISSOURI
MISSISSIPPI COUNTY
MISSISSIPPI RIVER
OHIO RIVER
ST. LOUIS DISTRICT
MEMPHIS DISTRICT
MISSOURI PACIFIC
GULF MOBILE AND OHIO
ILLINOIS CENTRAL
NEW YORK CENTRAL
Mounds
Mound City
Cache
Beechridge
DIVERSION CHANNEL
OLD RIVER
Urbandale
North Cairo
Future City
Eliza Point
Cairo
Cairo Point
Birds Point
LIMIT OF PROJECT
Abies Point
Brewer Point
Thompson Ldg
Brooks Point
APPROXIMATE STATE BOUNDARY LINE
HURRICANE FIELD
DOGTOOTH ISLAND
DOGTOOTH BEND
ORIENT FIELD
ELK ISLAND
GREENFIELD BEND
SALADIN FIELD
S/C 21
S/C 22
S/C 23
S/C 24
S/C 25
LEGEND
EXISTING REVETMENT
EXISTING DIKES
LEVEE
S/C SIDE CHANNEL
BLUFF
River mileage originates at Mouth of Ohio River
RIVER AND HARBOR PROJECT
MISSISSIPPI RIVER
BETWEEN THE
OHIO AND MISSOURI RIVERS
MILE 0.0 TO MILE 25.8
SCALE IN FEET
4000 0 4000 8000
U. S. ARMY ENGINEER DISTRICT, ST. LOUIS
CORPS OF ENGINEERS
ST. LOUIS, MISSOURI
JUNE 30, 1970

APPENDIX A: MEAN VALUES FOR PHYSICAL-CHEMICAL AND BIOLOGICAL VARIABLES AND LEAST SIGNIFICANT DIFFERENCE (LSD) VALUES FOR SIDE CHANNELS DURING SAMPLING PERIODS I, II, AND III

Mean Values for Physical-Chemical and Biological Variables and Least Significant Difference (LSD) Values for Side Channels During Sampling Periods I, II, III

	Physical-Chemical Variables Measured at Surface														
	Temperature, C			Dissolved Oxygen, mg/ℓ			Turbidity, JTU			pH			Total Alkalinity, mg/ℓ		
	Sampling Period			Sampling Period			Sampling Period			Sampling Period			Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1	25.3	29.3	29.7	5.2	6.1	6.0	291.7	111.7	80.0	8.0	7.7	7.9	154.7	143.7	216.0
2	25.0	28.3	--*	5.2	5.1	--	271.7	133.3	--	8.0	7.2	--	149.0	144.3	--
3	26.0	28.0	30.3	5.7	5.4	6.3	136.7	50.0	33.3	7.4	7.6	8.1	147.0	143.0	222.0
4	26.0	27.3	--	7.3	6.0	--	106.3	100.0	--	8.1	7.4	--	186.7	172.7	--
5	25.3	28.0	--	6.6	6.6	--	156.7	65.0	--	7.8	7.7	--	162.0	154.7	--
6	25.7	28.3	30.7	6.4	7.8	9.6	113.3	61.7	30.0	7.7	7.7	8.2	157.7	152.3	229.3
7	25.3	30.3	29.0	6.9	8.4	6.5	95.0	60.0	87.3	7.8	7.8	7.7	158.3	165.0	200.3
8	23.7	28.0	--	6.1	6.5	--	391.7	68.3	--	7.6	7.4	--	143.3	150.3	--
9	26.3	26.3	--	6.1	8.6	--	230.0	88.3	--	7.7	7.8	--	151.7	197.7	--
10	26.3	27.3	29.7	6.1	11.3	5.5	295.0	93.3	401.7	7.6	7.9	7.8	149.7	197.7	179.3
11	26.7	29.0	29.0	6.4	10.8	5.4	166.7	48.3	500.0	7.7	8.2	7.8	145.0	158.7	187.3
12	26.0	28.7	30.0	6.6	7.6	5.1	76.7	48.3	416.7	7.9	7.8	7.9	154.7	166.3	191.0
14	26.7	29.3	--	8.1	11.2	--	105.0	33.3	--	7.9	8.1	--	209.7	175.3	--
15	26.0	29.7	33.3	6.8	10.9	12.1	76.7	33.3	36.7	7.6	8.3	8.6	153.3	157.7	206.0
16	26.3	30.0	29.3	6.5	8.7	6.5	96.7	23.3	43.3	7.2	7.9	7.7	146.7	158.0	207.3
17	28.7	24.7	31.0	6.7	7.1	7.1	148.3	85.0	45.7	7.8	7.7	8.0	144.7	145.0	209.3
18	28.0	26.0	--	6.3	7.8	--	121.7	73.3	--	7.7	7.7	--	163.3	160.7	--
19	26.3	24.3	28.0	6.4	7.5	4.6	175.0	76.7	473.3	7.4	7.6	7.6	147.7	144.3	172.0
20	25.7	25.3	28.0	6.4	7.6	5.4	83.3	61.7	500.0	7.6	7.7	7.8	149.3	140.7	197.3
21	26.7	26.3	--	7.2	8.9	--	48.3	51.7	--	7.9	7.9	--	162.3	185.7	--
22	26.0	26.7	--	8.8	12.9	--	38.3	66.7	--	7.4	7.6	--	335.0	377.7	--
23	28.0	26.0	31.0	6.6	7.8	7.6	71.7	90.0	51.7	7.9	7.7	8.0	154.7	161.7	217.3
24	26.3	30.0	--	7.4	10.8	--	56.7	23.3	--	7.6	8.0	--	164.7	197.7	--
Approx LSD	1.52	1.89	1.36	0.99	3.12	1.66	99.48	41.90	71.24	0.18	0.36	0.30	45.40	55.93	12.23

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(1 of 11 sheets)

Physical-Chemical Variables Measured at Bottom

Location	Temperature, C Sampling Period I	II	III	Dissolved Oxygen, mg/ℓ Sampling Period I	II	III	Turbidity, JTU Sampling Period I	II	III	pH Sampling Period I	II	III	Total Alkalinity, mg/ℓ Sampling Period I	II	III
1	25.3	29.3	29.7	5.4	6.1	6.4	376.7	141.7	85.7	7.8	7.7	7.9	155.0	144.7	217.7
2	25.0	28.0	--	5.1	4.9	--	271.7	155.0	--	7.9	7.3	--	149.7	143.0	--
3	25.3	28.0	28.0	5.2	5.3	4.9	178.3	55.0	68.3	7.3	7.6	7.8	151.3	144.3	224.3
4	25.7	27.3	--	4.7	3.3	--	145.0	128.3	--	8.1	7.5	--	187.0	173.7	--
5	25.3	27.7	--	6.4	5.0	--	191.7	101.7	--	7.9	7.6	--	161.7	158.7	--
6	23.7	27.3	24.0	3.6	2.9	0.5	140.0	51.7	23.3	7.5	7.6	7.2	166.0	151.7	290.3
7	24.7	28.7	27.7	4.9	4.5	3.2	161.7	70.0	168.3	7.5	7.7	7.4	158.0	164.3	220.7
8	23.7	28.0	--	6.0	6.5	--	416.7	76.7	--	7.6	7.5	--	146.7	151.3	--
9	23.7	26.3	--	3.9	7.0	--	290.0	123.3	--	7.6	7.8	--	155.3	197.0	--
10	25.3	26.5	29.7	5.9	9.2	5.5	371.7	115.0	480.0	7.7	7.7	7.8	150.0	188.0	180.3
11	25.7	27.7	28.7	6.4	7.1	5.5	196.7	56.7	500.0	7.7	7.8	7.8	145.3	156.7	187.0
12	24.7	26.7	29.3	4.9	5.0	5.1	123.3	166.7	500.0	7.5	7.6	7.9	157.0	170.3	189.0
14	26.0	26.7	--	6.0	7.1	--	170.0	95.0	--	7.4	7.7	--	214.3	187.3	--
15	24.0	26.0	28.3	3.6	4.1	0.4	86.7	90.0	61.7	7.2	7.5	7.3	205.3	174.0	235.3
16	25.0	26.7	29.0	5.6	5.6	6.8	145.0	46.7	110.0	7.0	7.5	7.9	146.3	159.7	209.3
17	27.3	24.0	29.0	6.2	6.5	6.7	188.3	95.0	80.0	7.9	7.8	7.8	146.7	145.0	213.3
18	27.7	25.0	--	6.2	7.0	--	135.0	91.7	--	7.7	7.7	--	162.3	161.0	--
19	26.3	24.0	28.0	6.4	7.2	5.0	193.3	106.7	500.0	7.5	7.7	7.7	149.3	145.7	170.3
20	24.7	24.3	28.0	6.2	6.2	5.2	135.0	76.7	500.0	7.7	7.7	7.8	149.7	142.3	199.0
21	24.7	24.7	--	4.3	6.1	--	113.3	50.0	--	7.6	7.6	--	227.0	185.3	--
22	20.7	21.7	--	1.4	3.4	--	48.3	110.0	--	6.7	7.0	--	634.7	597.7	--
23	26.0	24.3	29.3	4.0	5.2	5.5	215.0	138.3	53.3	7.5	7.5	7.7	156.7	163.0	215.3
24	26.0	24.7	--	5.7	1.4	--	76.7	41.7		7.4	7.3	--	154.3	202.0	--
Approx LSD	2.01	2.74	1.77	2.28	2.46	1.04	119.74	69.72	68.26	0.57	0.43	0.22	77.64	92.03	27.32

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(2 of 11 sheets)

	Benthos**														
	Total No. Sampling Period			No. m/2 Sampling Period			Diversity $\bar{d}$ Sampling Period			Eveness e Sampling Period			Taxa Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1		91.0	14.0		162.9	25.1		2.10	2.53		0.62	0.92		10.7	6.7
2		350.0	--		626.5	--		2.18	--		0.60	--		14.7	--
3		103.7	60.3		185.6	108.0		1.67	1.93		0.58	0.62		7.3	11.0
4		666.0	--		1194.6	--		1.21	--		0.38	--		7.7	--
5		156.7	--		280.4	--		1.61	--		0.62	--		6.0	--
6		360.0	97.0		644.4	173.7		1.00	1.11		0.35	0.60		7.7	4.7
7		88.3	69.3		158.1	124.1		1.01	--		0.65	0.64		3.3	4.7
8		265.0	--		481.0	--		1.32	1.42		0.52	--		5.7	--
9		475.0	--		872.5	--		1.41	--		0.54	--		6.7	--
10		213.7	140.3		382.5	251.2		1.40	0.95		0.48	0.32		7.3	8.3
11		147.7	27.7		264.3	49.5		1.39	2.43		0.46	0.80		7.7	9.0
12		177.3	52.0		317.4	93.1		0.97	1.24		0.44	0.47		4.3	5.3
14		252.0	--		451.1	--		1.49	--		0.66	--		5.0	--
15		222.3	152.0		398.0	272.1		1.52	0.86		0.52	0.36		7.7	5.0
16		144.7	41.0		259.0	73.4		1.22	1.50		0.45	0.58		6.3	6.0
17		62.7	8.7		112.2	15.5		2.16	0.92		0.68	0.87		9.3	2.3
18		117.7	--		210.6	--		1.75	--		0.73	--		5.7	--
19		198.0	43.7		354.4	78.2		1.16	1.44		0.38	0.54		8.3	6.7
20		188.7	104.0		337.7	186.2		0.44	0.80		0.19	0.39		5.0	6.7
21		152.0	--		272.1	--		1.78	--		0.67	--		6.3	--
22		974.0	--		1741.8	--		1.44	--		0.58	--		5.7	--
23		644.3	157.0		1153.4	281.0		1.54	1.73		0.51	0.53		8.3	9.5
24		1120.0	--		2004.8	--		1.41	--		0.56	--		5.0	--
Approx LSD		338.86	105.64		601.98	189.10		0.82	1.32		0.26	0.40		3.87	7.7

* Dash indicates that no sample was taken; blank that there was no sampling during period.
** Values based on two composite Petersen dredge hauls (0.15 m^2).

(3 of 11 sheets)

	Benthos (Concluded)																	
	Insecta Sampling Period			Oligochaeta Sampling Period			Hirudinea Sampling Period			Crustacea Sampling Period			Pelecypoda Sampling Period			Gastropoda Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1		39.7	9.0		49.3	4.0		0.3	0.0		0.0	0.0		1.3	0.0		0.3	0.0
2		219.7	--		119.0	--		0.3	--		0.7	--		9.0	--		1.3	--
3		39.0	45.7		64.3	12.3		0.0	0.3		0.0	0.7		0.3	0.7		0.0	0.0
4		131.7	--		534.0	--		0.0	--		0.0	--		0.3	--		0.0	--
5		89.7	--		67.0	--		0.0	--		0.0	--		0.0	--		0.0	--
6		206.0	16.3		153.7	80.6		0.3	0.0		0.0	0.0		0.0	0.3		0.0	0.0
7		23.3	49.7		65.0	19.7		0.0	0.0		0.0	0.0		0.0	0.3		0.0	0.0
8		84.0	--		177.7	--		0.0	--		0.0	--		3.3	--		0.0	--
9		204.0	--		271.0	--		0.0	--		0.0	--		0.0	--		0.0	--
10		62.3	33.3		149.7	104.0		0.3	0.0		0.0	0.3		1.0	2.3		0.3	0.3
11		36.7	16.3		103.7	9.0		0.0	0.0		0.0	0.0		7.3	1.3		0.0	1.0
12		22.0	3.0		155.3	47.3		0.0	0.0		0.0	0.3		0.0	1.0		0.0	0.3
14		196.7	--		52.3	--		0.0	--		0.0	--		3.0	--		0.0	--
15		102.0	56.7		119.0	92.7		0.0	0.0		0.0	0.0		1.3	2.7		0.0	0.0
16		44.7	10.3		119.7	25.3		0.0	0.0		0.0	0.0		0.3	5.3		0.0	0.0
17		40.7	3.7		19.0	2.7		0.3	0.0		0.0	0.0		2.3	2.3		0.3	0.0
18		77.3	--		40.3	--		0.0	--		0.3	--		0.0	--		0.0	--
19		54.7	6.7		137.7	34.3		0.0	0.0		0.0	0.0		5.7	2.0		0.0	0.7
20		10.3	20.7		178.0	82.7		0.0	0.0		0.0	0.0		0.3	0.3		0.0	0.3
21		94.7	--		57.0	101.5		0.0	--		0.0	--		0.0	--		0.3	--
22		534.3	--		438.0	--		0.0	--		0.0	--		0.3	--		0.3	--
23		244.3	54.5		394.0	--		0.0	0.0		0.0	0.0		5.3	1.0		0.7	0.0
24		581.3	--		538.3	--		0.0	--		0.0	--		0.0	--		0.3	--
Approx LSD		168.49	73.98		252.16	110.74		0.44	0.33		0.28	0.80		7.55	6.13		1.11	1.03

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(4 of 11 sheets)

	Phytoplankton											
	Diversity $\bar{d}$ Sampling Period			Eveness e Sampling Period			Chlorophyta, No./ℓ Sampling Period			Euglenophyta, No./ℓ Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III
1	3.58	3.01	2.07	0.84	0.84	0.67	3725.0	271.3	85	3221.0	370.0	45.0
2	3.59	2.93	--	0.79	0.86	--	2962.7	0.0	--	3174.7	444.0	--
3	3.29	2.03	1.98	0.83	0.72	0.65	1517.3	112.0	76.7	995.0	19.0	83.3
4	3.05	2.64	--	0.78	0.84	--	2032.0	287.7	--	4494.7	609.0	--
5	3.04	2.85	--	0.80	0.79	--	873.0	345.3	--	1938.7	419.3	--
6	3.19	2.28	2.27	0.79	0.72	0.78	3363.0	315.7	40.0	2488.0	740.7	90.0
7	3.01	1.82	1.46	0.84	0.69	0.73	930.7	131.3	--	902.3	246.7	360.0
8	2.92	3.02	--	0.85	0.88	--	610.7	295.3	--	785.7	723.3	--
9	3.00	2.71	--	0.84	0.68	--	669.0	8197.0	--	640.3	641.7	--
10	2.70	3.16	1.67	0.89	0.83	0.89	722.0	723.7	35.0	524.3	1928.0	30.0
11	3.66	2.94	0.50	0.85	0.61	0.50	4467.0	568.0	10.0	1954.0	1456.7	10.0
12	2.95	3.15	1.77	0.75	0.85	0.76	1350.0	518.0	40.0	2250.0	296.0	20.0
14	2.87	3.11	--	0.70	0.82	--	2740.6	1221.0	--	6592.7	666.3	--
15	2.84	1.94	2.15	0.70	0.90	0.84	2995.0	74.0	25.0	2830.0	37.0	115.0
16	2.87	3.03	2.27	0.73	0.76	0.82	4728.3	703.0	5.0	2243.0	481.0	50.0
17	2.95	2.88	2.54	0.89	0.77	0.85	611.0	666.0	20.0	582.7	386.3	110.0
18	2.97	3.03	--	0.77	0.81	--	6407.3	763.3	--	3380.3	320.7	--
19	2.24	3.15	1.00	0.82	0.80	1.00	628.2	765.0	20.0	343.7	261.3	20.0
20	3.37	3.22	1.46	0.79	0.84	0.98	2911.0	715.3	10.0	1389.0	320.7	10.0
21	2.72	2.86	--	0.68	0.81	--	2008.0	2020.0	--	2979.7	1201.0	--
22	2.53	2.91	--	0.84	0.79	--	576.3	6946.3	--	1328.0	1064.7	372.7
23	2.71	3.07	2.50	0.86	0.89	0.83	465.7	715.3	20.0	383.7	616.7	90.0
24	2.26	2.81	--	0.60	0.77	--	4632.3	518.0	--	3795.0	1866.3	--
Approx LSD	0.68	1.11	1.48	0.14	0.25	0.69	1763.5	6290.17	58.64	2731.24	4232.93	116.68

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(5 of 11 sheets)

	Phytoplankton (Concluded)											
	Chrysophyta, No./ℓ			Cyanophyta, No./ℓ			Cryptophyta, No./ℓ			Total, No./ℓ		
	Sampling Period			Sampling Period			Sampling Period			Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III
1	5800.0	1443.0	942.5	1738.3	227.0	22.5	1218.3	24.7	0.0	15702.7	2336.0	1095.0
2	5545.7	1147.0	--	697.7	148.0	--	427.3	148.0	--	12808.0	1887.0	--
3	4187.0	1327.3	600.0	346.3	271.0	6.7	236.7	0.0	0.0	7282.3	1730.0	766.7
4	2089.7	1431.0	--	87.3	106.7	--	00.0	0.0	--	8703.7	2434.3	--
5	1768.3	1267.0	--	116.0	419.3	--	29.0	74.0	--	4725.0	2525.0	--
6	5571.7	4560.0	215.0	727.3	88.7	10.0	1078.7	0.0	0.0	13228.7	5651.0	355.0
7	1309.7	979.0	30.0	87.0	2.0	--	0.0	0.0	--	3229.7	1359.0	390.0
8	1601.0	1834.3	--	233.0	0.0	--	0.0	164.3	--	3230.3	3017.3	--
9	1920.0	1488.3	--	262.0	0.0	--	0.0	49.3	--	3491.3	10376.3	--
10	1554.3	4625.0	95.0	232.7	428.3	10.0	0.0	33.0	0.0	3033.3	7738.0	170.0
11	3335.0	2048.3	30.0	624.3	329.3	--	1588.0	0.0	--	11968.3	4402.3	50.0
12	3952.0	1555.0	140.0	392.7	0.0	--	294.3	0.0	--	8239.0	2369.0	200.0
14	3595.7	2443.0	--	319.7	0.0	--	58.3	98.7	--	13307.0	4774.5	--
15	5521.0	481.0	140.0	890.0	0.0	--	416.0	0.0	--	12652.3	592.0	280.0
16	7974.0	1999.0	335.0	387.3	333.0	5.0	7203.0	0.0	0.0	22535.7	2344.0	395.0
17	1985.0	2007.0	520.0	175.0	350.0	10.0	0.0	0.0	0.0	3353.7	3409.7	660.0
18	6299.7	2000.7	--	705.0	228.3	--	3716.7	24.7	--	20509.0	3337.7	--
19	1059.3	2591.3	--	174.7	271.3	0.0	0.0	0.0	0.0	2206.0	3889.0	40.0
20	3437.7	1825.7	50.0	624.3	197.3	0.0	191.3	0.0	0.0	8553.3	3059.0	70.0
21	4610.3	1455.0	--	100.0	106.3	--	33.3	0.0	--	9731.3	4782.3	--
22	372.7	2031.7	--	203.7	724.0	--	0.0	125.3	--	2480.7	19992.0	--
23	1173.0	1501.0	260.0	160.0	345.3	0.0	0.0	0.0	0.0	2182.3	3182.3	185.0
24	7147.7	1230.0	--	358.0	589.3	--	2908.7	--	--	18841.6	4205.7	--
Approx LSD	2487.00	2969.88	219.74	676.39	445.79	25.76	2580.20	197.33	0.0	6208.45	9351.76	330.17

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(6 of 11 sheets)

	Zooplankton											
	Diversity $\bar{d}$			Eveness e			Total, No./ℓ			Cladocera, No./ℓ		
	Sampling Period			Sampling Period			Sampling Period			Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III
1	2.48	2.42	1.26	0.76	0.83	0.50	130.3	83.0	51.0	5.9	13.4	0.0
2	2.70	2.47	--	0.80	0.89	--	143.4	52.0	--	3.9	8.5	--
3	2.26	1.99	1.44	0.71	0.75	0.66	63.2	35.8	13.9	3.2	3.0	0.3
4	2.85	2.02	--	0.77	0.81	--	219.4	77.6	--	11.1	9.0	--
5	2.48	2.04	--	0.74	0.79	--	50.1	37.7	--	0.4	6.7	--
6	1.92	1.77	2.09	0.64	0.71	0.77	80.1	55.2	20.2	14.8	6.8	1.6
7	2.59	1.76	--	0.80	0.79	--	83.9	49.4	1.0	10.8	10.0	0.0
8	2.51	2.33	--	0.79	0.80	--	62.7	48.4	--	10.6	1.9	--
9	2.21	1.69	--	0.81	0.73	--	39.8	29.8	--	2.2	4.5	--
10	2.35	1.79	0.20	0.82	0.66	0.17	17.7	202.7	23.6	1.6	6.1	0.0
11	1.87	2.03	0.16	0.67	0.72	0.16	22.5	80.7	23.5	2.8	10.1	0.0
12	2.06	2.28	0.11	0.80	0.89	0.11	10.6	66.2	50.4	0.4	2.0	0.0
14	2.69	1.37	--	0.80	0.53	--	165.3	35.7	--	7.8	0.0	--
15	2.57	2.01	1.74	0.83	0.82	0.75	35.8	9.6	16.6	7.7	1.7	6.2
16	2.42	2.48	1.40	0.80	0.83	0.66	26.0	52.2	7.2	2.2	3.5	0.8
17	2.18	2.32	0.96	0.80	0.82	0.96	14.6	37.5	5.3	1.1	1.1	3.3
18	1.57	2.34	--	0.52	0.82	--	62.8	112.3	--	2.6	11.7	--
19	2.00	2.50	0.00	0.70	0.84	0.00	66.8	60.0	0.0	4.8	0.7	0.0
20	1.38	2.71	0.00	0.69	0.89	0.00	11.0	27.5	2.4	4.1	0.2	0.0
21	2.21	2.58	--	0.79	0.85	--	30.8	191.8	--	1.1	29.9	--
22	2.69	1.77	--	0.81	0.69	--	118.5	78.0	--	4.3	10.1	0.7
23	2.36	1.72	0.95	0.75	0.67	0.34	69.2	87.2	41.6	5.2	24.5	--
24	2.68	2.30	--	0.85	0.82	--	75.1	88.9	--	9.8	6.9	--
Approx LSD	0.69	1.04	0.53	0.22	0.29	0.37	82.30	92.02	48.04	7.22	20.43	5.7

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(7 of 11 sheets)

	Zooplankton (Concluded)											
	Copepoda, No./ℓ			Rotifera eggs No./ℓ			Adult Rotifera No./ℓ			Protozoa, No./ℓ		
	Sampling Period			Sampling Period			Sampling Period			Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III
1	30.6	15.9	2.5	58.1	3.4	0.2	21.5	22.5	6.7	14.2	27.8	41.7
2	23.7	7.5	--	65.6	0.5	--	19.1	12.0	--	31.0	23.5	--
3	23.9	19.1	8.9	11.3	1.6	0.2	22.8	11.2	2.1	2.1	0.8	2.4
4	8.6	8.8	--	40.5	16.0	--	135.1	25.5	--	24.1	18.3	--
5	11.1	14.2	--	15.0	2.1	--	13.7	9.9	--	9.8	4.8	--
6	12.3	14.4	2.5	7.7	6.0	5.4	11.6	9.6	6.1	33.6	18.3	4.6
7	20.7	10.2	1.0	7.6	3.4	0.0	17.3	13.8	0.0	27.6	11.9	0.0
8	9.6	16.3	--	12.6	0.0	--	6.7	15.6	--	23.3	14.6	--
9	14.6	5.4	--	6.3	0.5	--	8.4	17.0	--	8.3	2.4	--
10	6.6	5.3	0.2	2.2	34.1	0.0	3.8	128.1	1.0	3.5	29.0	22.5
11	11.1	12.2	--	3.6	15.4	0.0	3.5	34.2	1.0	1.5	8.7	22.5
12	4.6	9.5	--	1.3	39.7	0.0	3.5	10.6	0.7	0.7	4.3	49.7
14	16.1	1.9	--	55.5	13.8	--	79.6	14.0	--	6.2	6.0	--
15	9.9	1.9	7.8	4.6	1.4	0.0	9.9	2.6	2.7	3.7	2.0	0.0
16	9.1	16.1	5.0	2.8	4.4	0.0	9.7	18.6	1.4	2.2	9.6	0.0
17	7.0	4.2	2.0	0.0	2.0	0.0	3.9	14.3	0.0	2.6	15.8	0.0
18	3.3	15.3	--	18.9	12.8	--	29.5	45.7	--	8.3	26.9	--
19	6.7	5.3	--	0.6	5.0	0.0	8.3	20.3	0.0	46.4	28.6	0.0
20	1.7	3.4	2.4	0.8	4.3	0.0	2.2	14.3	0.0	2.2	5.3	0.0
21	4.6	9.4	--	3.3	29.7	--	5.4	73.6	--	16.3	49.2	--
22	4.4	9.9	--	52.8	10.3	--	43.8	45.4	--	13.3	2.3	--
23	3.2	6.7	5.0	10.2	3.6	0.0	18.7	9.1	35.9	31.9	43.4	0.0
24	14.8	19.5	--	15.5	15.6	--	29.5	23.1	--	5.4	23.8	--
Approx LSD	9.71	16.45	7.57	29.95	35.57	2.22	51.75	40.57	3.69	17.97	32.52	43.10

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(8 of 11 sheets)

	Fish																	
	Total No.†			Total Young-of-Year			Total Adult/Juvenile			Diversity $\bar{d}$			Eveness e			Commercial (Young-of-Year)		
	Sampling Period			Sampling Period			Sampling Period			Sampling Period			Sampling Period			Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1		92.0	58.0		80.0	50.0		12.0	8.0		0.0	2.22		0.00	0.71		1.0	0.7
2		82.0	86.0		32.0	81.0		50.0	5.0		1.70	0.92		0.57	0.39		1.0	2.3
3		411.0	144.7		254.7	142.7		156.3	2.0		1.10	1.92		0.37	0.56		0.3	0.0
4		248.0	169.7		160.7	165.0		87.3	4.7		1.95	2.66		0.60	0.68		8.7	24.7
5		64.7	241.7		37.0	236.7		27.7	5.0		2.21	1.98		0.73	0.62		1.0	12.0
6		157.0	365.7		99.0	361.0		58.0	4.7		1.64	1.46		0.54	0.39		4.3	21.0
7		77.0	103.5		56.0	103.5		21.0	0.0		2.42	1.84		0.73	0.58		4.7	18.5
8		22.7	114.7		10.0	105.0		12.7	9.7		1.72	2.53		0.76	0.74		1.7	49.3
9		103.7	123.3		63.3	123.0		40.3	0.3		1.45	1.85		0.55	0.60		2.0	37.7
10		85.0	101.3		49.7	98.3		35.3	3.0		2.08	2.27		0.71	0.66		0.7	47.3
11		102.0	48.0		76.3	47.3		25.7	0.7		1.76	1.93		0.65	0.72		0.3	24.7
12		45.3	210.5		39.0	202.0		6.3	8.5		1.39	2.62		0.52	0.70		0.0	39.5
14		224.7	443.7		204.0	440.3		20.7	3.3		1.68	1.49		0.55	0.41		1.7	12.3
15		48.0	138.7		33.3	135.0		14.7	3.7		2.02	1.81		0.79	0.58		0.3	30.7
16		127.0	42.7		93.7	36.7		33.3	6.0		1.74	2.63		0.62	0.81		0.0	13.0
17		39.7	30.3		18.0	27.3		21.7	3.0		0.92	2.36		0.50	0.75		0.0	1.7
18		77.7	131.7		62.7	115.0		15.0	16.7		1.41	2.13		0.64	0.59		0.0	14.7
19		26.0	43.0		11.0	36.7		15.0	7.7		1.31	2.04		0.72	0.67		1.3	4.0
20		73.7	95.3		55.7	94.7		18.0	0.7		2.28	2.00		0.75	0.67		1.7	7.0
21		129.0	109.7		104.7	103.3		24.3	6.3		1.72	2.32		0.60	0.69		0.3	67.0
22		162.0	84.7		137.0	77.7		25.0	6.7		1.62	2.48		0.54	0.67		6.7	6.0
23		61.0	95.3		44.0	89.7		17.0	5.7		2.43	1.82		0.77	0.54		2.3	4.3
24		118.0	129.0		110.0	108.3		8.0	20.7		1.60	2.31		0.52	0.65		0.7	16.3
Approx LSD		165.00	224.78		185.43	224.32		72.18	14.74		1.01	1.49		0.31	0.41		5.00	38.84

† Based on six hauls using 25-ft nylon seine, 3/16-in. mesh, 4-ft deep.

(9 of 11 sheets)

	Fish (Continued)																	
	Forage (Young-of-Year) Sampling Period			Predator (Young-of-Year) Sampling Period			Sport (Young-of-Year) Sampling Period			Commercial (Adult/Juvenile) Sampling Period			Forage (Adult/Juvenile) Sampling Period			Predator (Adult/Juvenile) Sampling Period		
Location	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
1		56.0	35.7		0.0	0.3		23.0	13.3		0.0	0.0		9.0	5.7		0.0	0.0
2		26.0	77.0		0.0	0.3		5.0	1.3		1.0	0.0		48.0	5.0		0.0	0.0
3		245.7	131.7		0.0	0.3		8.7	8.7		0.0	0.0		155.7	2.0		0.0	0.0
4		47.0	93.0		0.0	1.7		105.0	45.7		5.3	0.0		77.0	2.3		0.3	0.0
5		29.7	176.0		0.0	0.3		6.3	48.3		0.3	0.0		26.7	4.0		0.3	0.0
6		90.0	318.7		0.0	0.7		4.7	20.7		0.0	0.0		57.3	2.7		0.3	0.3
7		23.7	82.5		0.0	0.0		27.7	2.5		1.7	0.0		19.0	0.0		0.0	0.0
8		8.3	48.7		0.0	0.3		0.0	6.7		0.0	0.0		12.7	9.7		0.0	0.0
9		41.3	76.3		0.0	0.0		20.0	9.0		0.0	0.0		40.3	0.3		0.0	0.0
10		38.0	43.3		0.0	0.0		11.0	7.7		0.3	0.0		34.3	2.7		0.7	0.0
11		73.0	19.3		0.0	0.0		3.0	3.3		0.0	0.0		25.7	0.7		0.0	0.0
12		15.0	90.5		0.0	1.0		24.0	71.5		0.3	0.5		6.0	7.0		0.0	0.0
14		158.3	378.3		0.0	0.3		49.0	49.3		0.0	0.0		20.3	1.0		0.0	0.3
15		16.7	95.0		0.0	0.3		16.3	9.0		0.0	0.0		12.3	3.3		0.0	0.0
16		90.3	18.0		0.0	0.0		3.3	5.7		0.0	0.0		33.3	5.7		0.0	0.0
17		18.0	18.3		0.0	1.0		0.0	6.3		0.3	0.0		21.3	2.7		0.0	0.0
18		19.0	69.7		0.0	0.0		43.7	30.7		1.7	0.3		13.0	13.7		0.0	0.0
19		8.0	22.0		0.0	0.0		1.7	9.3		0.0	0.0		15.0	7.3		0.0	0.0
20		45.3	74.7		0.0	0.0		18.7	13.0		0.3	0.0		17.7	0.3		0.0	0.0
21		99.7	18.3		0.0	0.0		4.7	18.0		0.0	1.3		24.3	3.0		0.0	0.0
22		38.0	58.7		0.0	0.0		92.3	13.0		0.7	0.0		23.3	4.0		0.0	0.0
23		17.3	73.7		0.0	0.0		24.3	11.7		0.0	0.0		16.7	4.3		0.0	0.0
24		95.7	42.3		0.0	0.3		13.7	66.0		1.7	0.7		6.0	0.3		0.0	0.0
Approx LSD		166.98	225.07		0.0	1.07		64.61	45.49		4.44	1.15		73.88	0.35		0.67	0.35

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(10 of 11 sheets)

Location	Sport (Adult/Juvenile) Sampling Period I	II	III	Taxa Sampling Period I	II	III	Total Commerical Sampling Period I	II	III	Total Forage Sampling Period I	II	III	Total Predator Sampling Period I	II	III	Total Sport Sampling Period I	II	III
1		3.0	2.3		14.0	8.7		1.0	0.7		65.0	41.3		0.0	0.3		26.0	15.7
2		1.0	0.0		8.0	6.3		2.0	2.3		74.0	82.0		0.0	0.3		6.0	1.3
3		0.7	0.0		7.0	10.3		0.3	0.0		401.3	133.7		0.0	0.3		9.3	8.7
4		4.0	2.3		9.7	16.0		14.0	24.7		124.0	95.3		0.3	1.7		109.3	48.0
5		0.3	1.0		8.3	9.0		1.3	12.0		56.3	180.0		0.3	0.3		6.7	49.3
6		0.3	1.7		8.3	13.0		4.3	21.0		147.3	321.3		0.3	1.0		5.0	22.3
7		0.3	0.0		10.0	8.5		6.3	18.5		42.7	82.5		0.0	0.0		28.0	2.5
8		0.0	0.0		5.0	10.7		1.7	49.3		21.0	58.3		0.0	0.3		0.0	6.7
9		0.0	0.0		6.3	8.3		2.0	37.7		81.7	76.7		0.0	0.0		20.0	9.0
10		0.0	0.3		8.0	11.0		1.0	47.3		72.3	46.0		0.7	0.0		11.0	8.0
11		0.0	0.0		6.7	6.7		0.3	24.7		98.7	20.0		0.0	0.0		3.0	3.3
12		0.0	1.0		6.3	13.5		0.3	40.0		21.0	97.5		0.0	1.0		24.0	72.5
14		0.3	2.0		9.0	13.3		1.7	12.3		178.7	379.3		0.0	0.7		49.3	51.3
15		2.3	0.3		6.0	8.7		0.3	30.7		29.0	98.3		0.0	0.3		18.7	9.3
16		0.0	0.3		7.3	9.7		0.0	13.0		123.7	23.7		0.0	0.0		3.3	6.0
17		0.0	0.3		3.7	9.0		0.3	1.7		39.3	21.0		0.0	1.0		0.0	6.7
18		0.3	2.7		4.7	11.7		1.7	15.0		32.0	83.3		0.0	0.0		44.0	33.3
19		0.0	0.3		4.0	8.0		1.3	4.0		23.0	29.3		0.0	0.0		1.7	9.7
20		0.0	0.3		8.3	8.0		2.0	7.0		63.0	75.0		0.0	0.0		18.7	13.3
21		0.0	2.0		7.3	10.3		0.3	68.3		124.0	21.3		0.0	0.0		4.7	20.0
22		1.0	3.0		8.0	13.0		7.3	6.5		61.3	65.0		0.0	0.0		93.3	15.5
23		0.0	1.3		9.0	10.3		2.3	4.3		34.0	78.0		0.0	0.0		24.7	13.0
24		0.0	3.0		8.3	12.0		2.3	17.0		101.7	42.7		0.0	0.3		14.0	69.0
Approx LSD		1.90	4.66		3.98	5.62		4.61	39.59		146.04	228.31		0.67	1.14		65.43	46.58

Fish (Concluded)

* Dash indicates that no sample was taken; blank that there was no sampling during period.

(11 of 11 sheets)

APPENDIX B: SIMPLE CORRELATIONS AMONG BIOLOGICAL, PHYSICAL, CHEMICAL, AND MORPHOMETRIC VARIABLES FOR SIDE CHANNELS DURING SAMPLING PERIODS I, II, AND III

	TOTAL NUMBERS (BENTHOS)	NO. OF INSECTA (BENTHOS)	NO. OF OLIGOCHAETA (BENTHOS)	NO. OF TAXA (BENTHOS)	SPECIES DIVERSITY (d̄) (BENTHOS)
WATER TEMPERATURE	-.48** (106)	-.48** (106)	-.38** (106)	.07 (106)	.07 (106)
DISSOLVED OXYGEN	-.28** (106)	-.32** (106)	-.19* (106)	.13 (106)	.15 (106)
TURBIDITY	-.17 (106)	-.18 (106)	-.12 (106)	.07 (106)	.00 (106)
pH	-.43** (106)	.45** (106)	-.33** (106)	.10 (106)	.09 (106)
TOTAL ALKALINITY	.42** (106)	.49** (106)	.27** (106)	-.12 (106)	.01 (106)

	TOTAL FISH (FISH)	TOTAL YOUNG-OF-YEAR (FISH)	TOTAL ADULT/JUVENILE (FISH)	FORAGE FISH (FISH)	SPORT FISH (FISH)	SPECIES DIVERSITY (d̄) (FISH)
WATER TEMPERATURE	.09 (102)	.13 (102)	.06 (102)	.08 (102)	-.06 (102)	.27** (100)
DISSOLVED OXYGEN	-.06 (102)	-.07 (102)	-.00 (102)	.07 (102)	.13 (102)	.01 (100)
TURBIDITY	-.13 (102)	-.06 (102)	-.19 (102)	-.19* (102)	-.02 (102)	.16 (100)
pH	.00 (102)	.07 (102)	-.18 (102)	.03 (102)	-.15 (102)	.10 (100)
TOTAL ALKALINITY	.13 (102)	.19* (102)	-.14 (102)	.02 (102)	.32** (102)	.06 (100)
TOTAL NUMBERS (BENTHOS)	.06 (101)	.03 (101)	.10 (101)	-.02 (101)	.34** (101)	-.03 (99)
NO. OF INSECTA (BENTHOS)	.08 (101)	.06 (101)	.08 (101)	.03 (101)	.22* (101)	-.09 (99)
NO. OF OLIGOCHAETA (BENTHOS)	.03 (101)	-.00 (101)	.10 (101)	.07 (101)	.37** (101)	.02 (99)
NO. OF TAXA (BENTHOS)	-.07 (101)	-.09 (101)	.04 (101)	.05 (101)	-.09 (101)	.02 (99)
SPECIES DIVERSITY (d̄) (BENTHOS)	-.04 (101)	-.03 (101)	-.03 (101)	-.02 (101)	-.00 (101)	-.05 (99)

	TOTAL DENSITY (NO./ℓ) (PHYTOPLANKTON)	CHLOROPHYTA (NO./ℓ) (PHYTOPLANKTON)	CHRYSOPHYTA (NO./ℓ) (PHYTOPLANKTON)	SPECIES DIVERSITY (d̄) (PHYTOPLANKTON)
WATER TEMPERATURE	-.23** (156)	.16* (156)	-.20* (156)	-.29** (154)
DISSOLVED OXYGEN	.07 (156)	.15* (156)	.05 (156)	.13 (154)
TURBIDITY	-.02 (156)	.00 (156)	-.04 (156)	-.19* (154)
pH	-.16* (156)	-.07 (156)	-.17* (156)	-.00 (154)
TOTAL ALKALINITY	.11 (156)	.15 (156)	-.16* (156)	-.14 (154)
TOTAL NUMBERS (BENTHOS)	.48** (87)	.29 (87)	.14 (87)	.27** (87)
NO. OF INSECTA (BENTHOS)	.49** (87)	.29** (87)	.18 (87)	.22* (87)
NO. OF OLIGOCHAETA (BENTHOS)	.38** (87)	.23* (87)	.07 (87)	.27* (87)
NO. OF TAXA (BENTHOS)	-.03 (87)	-.03 (87)	.08 (87)	-.03 (87)
SPECIES DIVERSITY (d̄) (BENTHOS)	-.05 (85)	-.01 (85)	.00 (85)	-.12 (85)
TOTAL FISH (FISH)	.11 (84)	.07 (84)	.04 (84)	-.02 (82)
TOTAL YOUNG-OF-YEAR (FISH)	.08 (84)	.08 (84)	-.03 (84)	-.03 (82)
TOTAL ADULT/JUVENILE (FISH)	.11 (84)	.01 (84)	.23* (84)	.04 (82)
FORAGE FISH (FISH)	.03 (84)	.01 (84)	.07 (84)	-.03 (82)
SPORT FISH (FISH)	.34 (84)	.25 (84)	.01 (84)	.18 (82)
SPECIES DIVERSITY (d̄) (FISH)	.12 (84)	-.09 (84)	-.23* (84)	-.18 (82)

	TOTAL DENSITY (NO./ℓ) (ZOOPLANKTON)	NO. OF CLADOCERA (NO./ℓ) (ZOOPLANKTON)	NO. OF COPEPODA (NO./ℓ) (ZOOPLANKTON)	NO. OF ROTIFERA (ADULTS) (NO./ℓ) (ZOOPLANKTON)	NO. OF PROTOZOA (NO./ℓ) (ZOOPLANKTON)	SPECIES DIVERSITY (d̄) (ZOOPLANKTON)
WATER TEMPERATURE	-.12 (155)	.14 (153)	.02 (153)	-.05 (153)	-.02 (153)	-.37** (155)
DISSOLVED OXYGEN	.05 (155)	-.10 (153)	-.05 (153)	.16* (153)	.02 (153)	-.02 (155)
TURBIDITY	-.05 (155)	-.13 (153)	-.04 (153)	-.13 (153)	.07 (153)	-.31 (155)
pH	.07 (155)	-.10 (153)	-.04 (153)	.00 (153)	.06 (153)	-.10 (155)
TOTAL ALKALINITY	.17* (155)	-.03 (153)	.12 (153)	.19* (153)	-.13 (153)	-.04 (155)
TOTAL NUMBERS (BENTHOS)	.24* (86)	.20 (86)	.21* (86)	.14 (86)	.13 (86)	.16 (86)
NO. OF INSECTA (BENTHOS)	.23* (86)	.28** (86)	.18 (86)	.13 (86)	.15 (86)	.11 (86)
NO. OF OLIGOCHAETA (BENTHOS)	.21* (86)	.09 (86)	.20 (86)	-.13 (86)	.09 (86)	-.17 (86)
NO. OF TAXA (BENTHOS)	.04 (86)	.01 (86)	-.03 (86)	-.04 (86)	.09 (86)	-.04 (86)
SPECIES DIVERSITY (d̄) (BENTHOS)	.04 (86)	.15 (86)	-.01 (86)	-.00 (86)	.22 (86)	-.11 (86)
TOTAL FISH (FISH)	.00 (83)	.01 (83)	.17 (83)	.03 (83)	.06 (83)	.03 (83)
TOTAL YOUNG-OF-YEAR (FISH)	-.03 (83)	-.00 (83)	.16 (83)	-.07 (83)	-.06 (83)	-.02 (83)
TOTAL ADULT/JUVENILE (FISH)	.09 (83)	.06 (83)	.07 (83)	.11 (83)	.01 (83)	.17 (83)
FORAGE FISH (FISH)	-.02 (83)	-.02 (83)	.16 (83)	-.04 (83)	-.08 (83)	.07 (83)
SPORT FISH (FISH)	.12 (83)	.16 (83)	.13 (83)	.05 (83)	.06 (83)	.01 (83)
SPECIES DIVERSITY (d̄) (FISH)	-.00 (83)	.06 (83)	-.20 (83)	-.03 (83)	.07 (83)	-.30** (83)
TOTAL DENSITY (NO./ℓ) (PHYTOPLANKTON)	.22** (153)	.04 (153)	.17 (153)	.23** (153)	-.09 (153)	.27** (153)
CHLOROPHYTA (NO./ℓ) (PHYTOPLANKTON)	.12 (153)	.00 (153)	.05 (153)	.16 (153)	-.08 (153)	.05 (153)
CHRYSOPHYTA (NO./ℓ) (PHYTOPLANKTON)	.21** (153)	.04 (153)	.22** (153)	.16* (153)	-.05 (153)	.30** (153)
SPECIES DIVERSITY (d̄) (PHYTOPLANKTON)	.22** (153)	.14 (153)	.26** (153)	.12 (153)	.04 (153)	.52** (153)

	VOLUME	SURFACE AREA	RIVER STAGE	DISCHARGE	VELOCITY	SHORELINE DEVELOPMENT
WATER TEMPERATURE	.10 (141)	.02 (141)	.19** (177)	.11 (150)	-.02 (141)	-.02 (141)
DISSOLVED OXYGEN	.05 (141)	-.13 (141)	-.20** (177)	.15** (150)	-.12 (141)	.24** (141)
TURBIDITY	-.08 (141)	-.08 (141)	-.17* (177)	.68** (150)	.58** (141)	-.15 (141)
pH	.05 (141)	.10 (141)	.12 (177)	.06 (150)	.07 (141)	-.17 (141)
TOTAL ALKALINITY	-.16 (141)	-.04 (141)	-.23** (177)	.04 (150)	-.18* (141)	.30** (141)
TOTAL NUMBERS (BENTHOS)	-.35** (86)	.22 (86)	-.28 (107)	.19 (94)	-.21 (90)	.09 (86)
NO. OF INSECTA (BENTHOS)	.26* (86)	-.00 (86)	-.29** (107)	.19 (94)	-.19 (90)	.17 (86)
NO. OF OLIGOCHAETA (BENTHOS)	-.33** (86)	.35** (86)	.22* (107)	-.15 (94)	.20 (90)	.02 (86)
NO. OF TAXA (BENTHOS)	-.20 (86)	-.04 (86)	.18 (107)	.04 (94)	.28** (90)	-.04 (86)
SPECIES DIVERSITY (d̄) (BENTHOS)	.04 (86)	.08 (86)	.19* (107)	.00 (94)	.16 (90)	.13 (86)
TOTAL FISH (FISH)	-.16 (82)	.16 (82)	.24* (102)	-.16 (89)	-.23* (85)	-.18 (82)
TOTAL YOUNG-OF-YEAR (FISH)	-.12 (82)	.07 (82)	.17 (102)	-.11 (89)	-.18 (85)	-.15 (82)
TOTAL ADULT/JUVENILE (FISH)	-.13 (82)	.25* (82)	.25** (102)	-.18 (89)	-.19 (85)	-.13 (82)
FORAGE FISH (FISH)	-.11 (82)	.01 (82)	.24* (102)	-.16 (89)	-.23* (85)	-.19 (82)
SPORT FISH (FISH)	-.17 (82)	.48** (82)	-.00 (102)	-.13 (89)	-.16 (85)	.00 (82)
SPECIES DIVERSITY (d̄) (FISH)	-.00 (82)	.00 (82)	.04 (102)	.03 (89)	.04 (85)	.09 (82)
TOTAL DENSITY (NO./ℓ) (PHYTOPLANKTON)	.08 (125)	.02 (125)	-.12 (125)	-.19* (131)	.05 (122)	.20* (125)
CHLOROPHYTA (NO./ℓ) (PHYTOPLANKTON)	.01 (125)	-.01 (125)	-.10 (125)	-.16 (131)	-.08 (122)	.17* (125)
CHRYSOPHYTA (NO./ℓ) (PHYTOPLANKTON)	.12 (125)	-.02 (125)	-.00 (125)	-.19* (131)	.01 (122)	.04 (125)
SPECIES DIVERSITY (d̄) (PHYTOPLANKTON)	-.02 (125)	.04 (125)	.01 (125)	-.34** (131)	.09 (122)	.06 (125)
TOTAL DENSITY (NO./ℓ) (ZOOPLANKTON)	-.16 (123)	.28** (123)	.04 (155)	-.17* (131)	-.06 (122)	-.06 (123)
NO. OF CLADOCERA (NO./ℓ) (ZOOPLANKTON)	-.05 (123)	.09 (123)	-.06 (155)	-.13 (131)	-.10 (122)	-.07 (123)
NO. OF COPEPODA (NO./ℓ) (ZOOPLANKTON)	-.06 (123)	-.02 (123)	.31** (155)	-.10 (131)	.03 (122)	.02 (123)
NO. OF ROTIFERA (ADULTS) (NO./ℓ) (ZOOPLANKTON)	-.11 (123)	.39** (123)	-.02 (155)	-.17 (131)	-.16 (122)	-.05 (123)
NO. OF PROTOZOA (NO./ℓ) (ZOOPLANKTON)	-.11 (123)	.03 (123)	-.02 (155)	-.02 (131)	.16 (122)	-.10 (123)
SPECIES DIVERSITY (d̄) (ZOOPLANKTON)	-.02 (123)	.15 (123)	.00 (155)	-.37** (131)	-.09 (122)	.03 (123)

* SIGNIFICANT AT 5% LEVEL
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